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OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1891.

1809 3

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1891

CORRECTIONS.

Page 45, lines 8 and 16, for "forms" read "kinds."
Page 191, line 15, for 1886 read 1866.

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PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77.

John Robinson, 1878–79.

Edward A. Cowper, 1880–81.

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86.

Edward H. Carbutt, 1887–88.

Charles Cochrane, 1889.

Institution of Mechanical Engineers.

OFFICERS.

1891.

PRESIDENT.

JOSEPH TOMLINSON, ... London.

PAST-PRESIDENTS.

THE RT. HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., ... Northallerton.
SIR FREDERICK J. BRAMWELL, BART., D.C.L., F.R.S., ... London.
EDWARD H. CARBUTT, ... London.
CHARLES COCHRANE, ... Stourbridge.
THOMAS HAWKSLEY, F.R.S., ... London.
JEREMIAH HEAD, ... Middlesbrough.
JOHN RAMSBOTTOM, ... Alderley Edge.
JOHN ROBINSON, ... Leek.
PERCY G. B. WESTMACOTT, ... Newcastle-on-Tyne.

VICE-PRESIDENTS.

WILLIAM ANDERSON, D.C.L., F.R.S., ... Woolwich.
SIR JAMES N. DOUGLASS, F.R.S., ... London.
ALEXANDER B. W. KENNEDY, F.R.S., ... London.
ARTHUR PAGET, ... Loughborough.
SIR JAMES RAMSDEN, ... Barrow-in-Furness.
E. WINDSOR RICHARDS, ... Low Moor.

MEMBERS OF COUNCIL.

BENJAMIN A. DOBSON, ... Bolton.
SIR DOUGLAS GALTON, K.C.B., D.C.L., F.R.S., ... London.
JOHN HOPKINSON, JUN., D.Sc., F.R.S., ... London.
SAMUEL W. JOHNSON, ... Derby.
ARTHUR KEEN, ... Birmingham.
WILLIAM LAIRD, ... Birkenhead.
JOHN G. MAIR-RUMLEY, ... London.
HENRY D. MARSHALL, ... Gainsborough.
EDWARD B. MARTEN, ... Stourbridge.
EDWARD P. MARTIN, ... Dowlais.
WILLIAM H. MAW, ... London.
T. HURRY RICHES, ... Cardiff.
WILLIAM H. WHITE, C.B., F.R.S., ... London.
J. HARTLEY WICKSTEED, ... Leeds.
THOMAS W. WORSDELL, ... Arnside.

TREASURER.

HARRY LEE MILLAR.

SECRETARY.

ALFRED BACHE,

Institution of Mechanical Engineers, 19 *Victoria Street, Westminster, S.W.*

[Telegraphic address:—*Mech, London.*]

Institution of Mechanical Engineers.

ESTABLISHED 1847.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1891.

HONORARY LIFE MEMBERS.

1890. H. R. H. Albert Edward, Prince of Wales, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pall Mall, London, S.W.

1883. Abel, Sir Frederick Augustus, K.C.B., D.C.L., D.Sc., F.R.S., The Imperial Institute, Imperial Institute Road, London, S.W.; and 40 Cadogan Place, London, S.W. [*Imperial Institute, London.* 8743.]

1878. Crawford and Balcarres, The Right Hon. the Earl of, K.T., F.R.S., 2 Cavendish Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1889. Eiffel, Gustave, 37 Rue Pasquier, Paris.

1888. Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., Trinity College, Dublin.

1883. Kennedy, Professor Alexander Blackie William, F.R.S., 19 Little Queen Street, Westminster, S.W. [*Kinematic, London.*]

1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1888. Rosse, The Right Hon. the Earl of, K.P., D.C.L., LL.D., F.R.S., Birr Castle, Parsonstown.

MEMBERS.

1890. Abbott, Arthur Harold, care of Messrs. Octavius Steel and Co., Calcutta, India: (or care of F. C. Abbott, 101 Lambeth Palace Road, London, S.E.)

1878. Abbott, Thomas, Newark Boiler Works, Newark. [*Abbott, Newark.*]

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, 9 Disraeli Road, Upton, London, E.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing London.* 1854.]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1886. Adamson, Thomas Alfred, 27 Leadenhall Street, London, E.C.

1878. Adcock, Francis Louis, care of I. B. Roscoe, Central Jones Street, Kimberley, South Africa: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, Colehill Cottage, Fulham, London, S.W.

1889. Addy, George, Waverley Works, Effingham Road, Sheffield. [*Milling, Sheffield.*]

1887. Ahmed Bey, Colonel, Imperial Naval Arsenal, Constantinople.

1891. Ahrbecker, Henry Conrad Vandepoel, Morts Dock and Engineering Co., Balmain, Sydney, New South Wales.

1886. Aisbitt, Matthew Wheldon, 53 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and Savernake Lodge, Chelmsford.

1885. Alderson, George Becton, Messrs. Allen Alderson and Co., Alexandria, Egypt; The Lindens, Kew Road, R.O., Richmond, Surrey: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, Engineering Department, London County Council; and 9 Sheen Park, Richmond, Surrey.

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Co., Albert Works, Penistone Road, Sheffield.

1884. Allen, Alfred Evans, 37 Wellington Street, Hull.

1891. Allen, Marcus, Union Brass and Iron Works, Great Ancoats Street, and Phœnix Iron Works, Jersey Street, Manchester. [*Valves, Manchester. Nat.* 60.]

1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, 65 Bute Street, Bute Docks, Cardiff.

1885. Allen, William Henry, Messrs. W. H. Allen and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.

1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Allott, Charles Sneath, 4 Chapel Walks, Manchester.

1876. Allport, Charles James, Whitehall Club, Parliament Street, Westminster, S.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, Cartagena and Herrerias Steam Tramways, 43 Muralla del Mar, Cartagena, Spain: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and May Bank, Colby Road, Upper Norwood London, S.E. [*Drilling, London.*]

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1891. Anderson, Alexander Southerland, Chief Engineer, Ordnance Department, Ordnance Factory, Cawnpore, India.

1876. Anderson, Henry John Card, 13 Mount Ararat Road, Richmond, Surrey.

1890. Anderson, Herbert William, Messrs. Hilton Anderson and Co., Manor Works, Halling, near Rochester.

1856. Anderson, William, D.C.L., F.R.S., Director-General of Ordnance Factories, Royal Arsenal, Woolwich; and Lesney House, Erith, S. O., Kent.

1891. Anderson, William, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 22 Walbrook, London, E.C. [*Millwright, London.*]; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1891. Archbold, John, Eastwood Collieries, Eastwood, R.S.O., Notts.

1881. Archbold, Joseph Gibson, Manager, Blyth Dry Dock, Blyth, Northumberland.

1889. Archer, Charles Frederick, Messrs. Joseph Richmond and Co., 30 Kirby Street, Hatton Garden, London, E.C.

1874. Archer, David, Oldbury Railway-Carriage and Wagon Co., Oldbury, near Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.; and 13 Clifton Road, Brockley, London, S.E.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Messrs. Willans Arnold and Co., Spanish Steel Works, Sheffield.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow. [*Germiston, Glasgow.* 1080.]

1887. Arrol, Sir William, Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, 331½ Buen Orden, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 129A Winchester House, Old Broad Street, London, E.C.)

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Tardeo, Bombay, India.

1890. Ashley, Thomas James, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool.

1884. Ashwell, Frank, Victoria Foundry, Sycamore Lane, Leicester. [*Iron, Leicester.* 100.]

1891. Ashworth, Henry, Ollerton, Bolton.

1890. Askham, John Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1890. Askham, Philip Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1891. Asplen, Bernard, Machine Exchange, Southall.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1890. Aston, John W., Chief Teacher of Mechanical Science, Municipal School of Art, Birmingham; and Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham.

1889. Atkinson, Alexander, N. W. Hotel, Lahore, Punjaub, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1875. Atkinson, Edward (*Life Member*), The Projectile Company, New Road, Wandsworth Road, London, S.W.

1890. Atkinson, Edward Turner, London County Council, Spring Gardens, London. S.W.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1891. Bagshaw, Walter, Victoria Foundry, Batley.

1890. Bailey, Charles Stuart, Russell Mine, Montgomery County, North Carolina, United States.

1886. Bailey, William, 14 Delahay Street, Westminster, S.W.

1885. Bailey, William Henry, Albion Works, Salford, Manchester. [*Beacon, Salford.*]

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1887. Baillie, Robert Alexander, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 282 Rue Royale, Bruxelles, Belgium.

1890. Bain, George, Locomotive Department, Egyptian Government Railways, Cairo, Egypt.

1880. Bain, William Neish, 40 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1873. Baird, George, St. Petersburg; and Fulmer, Slough.

1890. Baker, Sir Benjamin, K.C.M.G., F.R.S. (*Life Member*), 2 Queen Square Place, Westminster, S.W.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Lala, Executive Engineer, Public Works Department, Punjaub, India; care of Lala Shamba Das, Said Mitha, Lahore, India.

1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.

1888. Baraclough, William Henry, Triangle Chambers, Martineau Street, Birmingham.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham.

1882. Barlow, Henry Bernoulli, 4 Mansfield Chambers, 17 St. Ann's Square, Manchester. [*Monopoly, Manchester.*]

1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1891. Barnes, John Edward Lloyd, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1881. Barnett, John Davis, Assistant Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.

1887. Barningham, James, 27 Corporation Street, Manchester.

1884. Barr, Archibald, D.Sc., Professor of Engineering, The University, Glasgow.

1878. Barr, James, care of William McConnell, Underwood House, Paisley.

1883. Barras, Harry Haywood, 7 Howard Street, Rotherham; and Broom Lodge, Rotherham.

1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Rochdale Road Station, Manchester.

1882. Barrett, John James, 5 Chinchpoogly Road, Bombay, India.

1885. Barrie, William, Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., Tokyo, Japan.

1887. Barringer, Herbert, 88 Bishopsgate Street Within, London, E.C.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury. [*Barrows, Banbury.*]

1871. Barry, John Wolfe, 21 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]

1883. Bartlett, James Herbert, Middlesbrough, Kentucky, United States.

1887. Bate, Capt. Charles McGuire, R.E., War Office, Whitehall, London, S.W.

1885. Bateman, Henry, Superintending Engineer, Rangoon Tramways, Rangoon, India.

1891. Bates, Henry, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester; and 30 Halliwell Terrace, Trafford Road, Salford, Manchester.

1891. Battle, Arthur Edwin, 359–361 Collins Street, Melbourne, Victoria: (or care of F. G. Battle, Whitehall, Potterhanworth, Lincoln.) [Reuter's Agency: *Battle, Melbourne.*]

1889. Bayford, William James, Engineer, Messrs. Meakin and Co., Brewers, Delhi, India.

1872. Bayliss, Thomas Richard, Belmont, Northfield, Birmingham.

1891. Baynes, John, Midland Railway-Carriage and Wagon Co., Suffolk House Laurence Pountney Hill, London, E.C.

1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1891. Beatty, Hazlitt Michael, Locomotive Superintendent, Western Railway, Cape Government Railways, Salt River, near Cape Town, Cape Colony; and Rosclare Camp Ground, Rondebosch, near Cape Town, Cape Colony.

1880. Beaumont, William Worby, 163 Strand, London, W.C.; and Melford, Palace Road, Tulse Hill, London, S.W.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, Enfield House, Fairlop Road, Leytonstone, London, N.E.

1891. Beckwith, George Charles, 2 Rutland Street, Swansea.

1875. Beckwith, John Henry, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1884. Beetlestone, George John, Sudbrook Works, near Chepstow.

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough; and Linthorpe, Middlesbrough. [*Bells, Middlesbrough.* 5510.]

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1880. Bell, William Henry, Vale Rectory, Guernsey.

1879. Bellamy, Charles James, 195 Earl's Court Road, South Kensington, London, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W [*Benham, London.* 7065.]

1887. Bennetts, Edward John, Battery Reef Gold Mine, P.O. Box 96, Krugersdorp, Transvaal, South Africa.

1890. Berkley, James Eustace, Locomotive and Carriage Superintendent, H.H. the Nizam's Guaranteed State Railways, Secunderabad, India.

1878. Berrier-Fontaine, Marc, Directeur des Constructions navales, Directeur de l'École nationale du Génie maritime, 27 Quai de la Tournelle, Paris: (or care of Messrs. P. S. King and Son, Canada Buildings, King Street, Westminster, S.W.)

1890. Bertram, Alexander, Wigan Coal and Iron Works, Wigan.

1891. Bertram, David Noble, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1887. Bertram, William, Messrs. George and William Bertram, St. Katherine's Works, Sciennes, Edinburgh.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1891. Best, Francis Edward, 1 Swan Walk, Chelsea Embankment, London, S.W.

1891. Bevis, Alfred William, School of Engineering Science and Agriculture, Folkestone.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, care of Bank of Bengal, Calcutta, India: (or 8 Canynge Square, Clifton, Bristol).

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1888. Billinton, Robert John, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1890. Bingham, Charles Henry, Messrs. Walker and Hall, Electro Works, Sheffield.

1887. Binnie, Alexander Richardson, Engineer, London County Council, Spring Gardens, London, S.W.; and 14 Campden Hill Gardens, Notting Hill, London, W.

1877. Birch, Robert William Peregrine, 5 Queen Anne's Gate, Westminster S.W.

1891. Bird, George, Messrs. James Bartle and Co., Western Iron Works, Notting Hill, London, W.

1847. Birley, Henry, 6 Brentwood, Pendleton, R.O., Manchester.

1888. Birtwistle, Richard, Messrs. S. S. Stott and Co., Laneside Foundry, Haslingden, Manchester.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead. [*Blackthorn, Newcastletyne.*]

1891. Black, William, 72 Bute Road, Cardiff.

1891. Blackburn, Arthur Henry, Engineer, Block Fuel Works, Grosvenor Wharf, Wharf Road, Cubitt Town, London, E.; and 9 Fenchurch Avenue, London, E.C.

1891. Blackburn, George William, Messrs. T. Green and Son, Smithfield Iron Works, Leeds.

1890. Blackburn, John, Resident Engineer, Colne Valley Water Works, Bushey, Watford.

1890. Blair, Peter Borrie, Messrs. Blair and Co., Stockton-on-Tees.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, Naval Construction and Armaments Works, Barrow-in-Furness.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, Catherine Chambers, 8 Catherine Street, Strand, London, W.C.

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1890. Booth, Robert, 110 Cannon Street, London, E.C.

1883. Booth, William Stanway, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1888. Borrows, William, Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helen's, Lancashire.

1891. Boswell, Samuel, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1885. Boughton, Henry Francis, Parade Chambers, Sheffield; and The Poplars, Stairfoot, Barnsley. [*Boughton, Barnsley. Nat.* 625, *Sheffield.*]

1886. Boult, Alfred Julius, Messrs. W. P. Thompson and Boult, 323 High Holborn, London, W.C.

1888. Boultbee, Frederic Richard, 46 Queen Victoria Street, London, E.C.; and 4 Loris Road, Shepherd's Bush, London, W.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1891. Bousfield, John Ebenezer, 4 South Street, Finsbury, London, E.C. [*Invention, London.* 169.]

1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. Bowen, Edward (*Life Member*), Locomotive and Carriage Superintendent, Porto Alegre and New Hamburg Railway, Rio Grande do Sol, Brazil: (or care of Benjamin Packham, 122 Upper Lewes Road, Brighton.)

1870. Bower, Anthony, Gayton Cottage, Heswall, near Chester.

1858. Bower, John Wilkes (*Life Member*), Meredale, Rugby Road, Leamington Spa.

1890. Boyd, John White, Superintendent Engineer, Hong Kong and Whampoa Dock Co., Hong Kong, China.

1884. Boyer, Robert Skeffington, Merchants' Exchange, Pier Head, Cardiff.

1882. Bradley, Frederic, Sandhills, Liverpool; Clensmore Foundry, Kidderminster; and Wolverley House, Southport.

1889. Bradley, Isaac, Manager, Gatling Gun Works, Perry Barr, Birmingham.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich. [*Braithwaite, Westbromwich.*]

1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., F.R.S., 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1888. Bratt, Augustus Hicks Henery, Mechanical Engineer, Prye Dock, Penang, Straits Settlements: (or Sunnyside, Old Trafford, Manchester.)

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's.

1889. Brebner, Samuel Gordon, Chief Mechanical Engineer, Small Arms Ammunition Factory, Poona, India.

1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham. [*Breeden, Birmingham.*]

1891. Brewster, Edwin Henry George, 12 Delahay Street, Westminster, S.W.

1890. Brewster, Walter Seckford, Messrs. Beyer Peacock and Co.; Halstead Lodge, Ocean Street, Woollahra, Sydney, New South Wales.

1883. Bricknell, Augustus Lea, 56 Arlington Road, Brixton, London, S.W.

1891. Bridie, Ronald Hope, 90 Cannon Street, London, E.C. [*Enwheeling, London.*]

1887. Brier, Henry, Scotch and Irish Oxygen Co., Rosehill Works, Polmadie, Glasgow.

1889. Briggs, Charles, Jun., care of Robert Briggs, Howden.

1881. Briggs, John Henry, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and Howden.

1889. Bright, Philip, Messrs. J. Tylor and Sons, 2 Newgate Street, London, E.C.

1886. Bright, William, Manager, Fairwood Tin-Plate Works, Gowerton, R.S.O., Glamorganshire.

1891. Broadbent, William, Messrs. Thomas Broadbent and Sons, Central Iron Works, Huddersfield. [*Broadbent, Huddersfield.* 102.]

1891. Brock, Cameron William Harrison, 3 Prince's Mansions, 68 Victoria Street, Westminster, S.W.

1865. Brock, Walter, Messrs. Denny and Brothers, Engine Works, Dumbarton.

1890. Brodie, John Alexander, City Engineer's Office, Liverpool.

1879. Brodie, John Shanks, Town Surveyor and Harbour Engineer, Town Hall, Whitehaven.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1890. Brogden, Thomas, Messrs. Appleby and Brogden, Sandside, Scarborough.

1884. Brook-Fox, Frederick George, Executive Engineer, South Indian Railway, Vellore, Madras Presidency, India: (or care of Messrs. H. S. King and Co., 65 Cornhill, London, E.C.)

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1891. Brotherhood, Arthur Maudslay, 15 and 17 Belvedere Road, Lambeth, London, S.E.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 94 Cromwell Road, South Kensington, London, S.W. [*Brotherhood, London.*]

1886. Brown, Andrew, Messrs. T. Cosser and Co., McLeod Road Iron Works, Kurrachee, India: (or care of P. B. Brown, Hecla Works, Sheffield.)

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1891. Brown, Arthur Mogg, P.O. Box 1260, Johannesburg, Transvaal, South Africa.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1879. Brown, Charles, Engineer, Bâle, Switzerland: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Manager, Ontario Bolt Works, Swansea, near Toronto, Ontario, Canada.

1889. Brown, Frederick Alexander William, Lieutenant R.A., Inspector of Ordnance Machinery, Mauritius: (or 42 Fermoy Road St. Peter's Park, London, W.)

1888. Brown, Frederick Gills, care of Commissioner, Australian Irrigation Colonies, 35 Queen Victoria Street, London, E.C.; and 9 Baskerville Road, Wandsworth Common, London, S.W.

1881. Brown, George William, Messrs. Huntley Boorne and Stevens, Reading Tin Works, Reading.

1863. Brown, Henry, Aldridge Road, Perry Barr, Birmingham.

1887. Brown, James, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne.

1884. Brown, Oswald, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1890. Brown, Robert, Manor House Engine Works, Far Cotton, Northampton.

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1887. Browne, Frederick John, Messrs. Austin Wood Browne and Co., Austin Foundry, Parkfield Street, Islington, London, N.

1874. Browne, Tomyns Reginald, Deputy Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1874. Bruce, Sir George Barclay, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W.

1889. Bruce, Robert, 30 Great St. Helen's, London, E.C.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 23 Roland Gardens, South Kensington, London, S.W.

1888. Bruff, Charles Clarke, Coalport China Co., Coalport, near Ironbridge, Salop.

1873. Brunel, Henry Marc, 21 Delahay Street, Westminster, S.W. [3024.]

1870. Brunlees, Sir James, F.R.S.E., 12 Victoria Street, Westminster, S.W.

1891. Brunner, Adolphus, 61 Königin Strasse, Munich, Bavaria: (or care of L. F. Brunner, 257 Romford Road, Forest Gate, London, E.)

1887. Brunton, Philip George, Resident Engineer, Department of Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Old Ford, London, E.

1888. Bryce-Douglas, Archibald Douglas, Naval Construction and Armaments Works, Barrow-in-Furness.

1873. Buckley, Robert Burton, Superintending Engineer, East Indian Railway, Arrah, Bengal, India; 27 Queensberry Place, South Kensington, London, S.W.: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1878. Buddicom, Harry William, Plas-Derwen, Abergavenny.

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile : (or care of Messrs. Rose-Innes Cox and Co., 90 Cannon Street, London, E.C.)

1881. Bulkley, Henry Wheeler, 149 Broadway, New York, United States.

1884. Bullock, Joseph Henry, General Manager, Pelsall Coal and Iron Works, near Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1891. Bumsted, Francis Dixon, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1884. Bunning, Charles Ziethen, The Borax Co., 2 Macri Khan, Constantinople.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China : (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Locomotive Superintendent, Costa Rica Railways, Cartago, Costa Rica : (or Gaisford House, Gaisford Street, Kentish Town, London, N.W.)

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1891. Burgess, Francis Chassereau Boughey, Kistna Bridge, East Coast Railway, Bezwada, Madras Presidency, India.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1878. Burnett, Robert Harvey, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Messrs. Stevenson and Burstal, 38 Parliament Street, Westminster, S.W.

1890. Burstall, Henry Robert John, 19 Little Queen Street, Westminster, S.W. ; and 76 King's Road, London, N.W.

1877. Burton, Clerke, Burghill, Charlton Kings, Cheltenham.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1891. Butler, James, Victoria Iron Works, Halifax ; and Longfield, Halifax.

1888. Butter, Frederick Henry, Carriage Department, Royal Arsenal, Woolwich ; and 4 Hanover Road, Brookhill Park, Plumstead.

1891. Butter, Henry Joseph, Messrs. Tannett Walker and Co., Leeds; and Claremont, Burrage Road, Plumstead.

1887. Caiger, Emery John, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1886. Cairnes, Frederick Evelyn, care of R. Price-Williams, 4 Victoria Mansions, 32 Victoria Street, Westminster, S.W.

1889. Callan, William, River Plate Fresh Meat Co., 2 Coleman Street, London, E.C.

1886. Cambridge, Henry, Stuart Chambers, Mount Stuart Square, Cardiff.

1877. Campbell, Angus, Logie, Mussoorie, N. W. Provinces, India.

1880. Campbell, Daniel, Messrs. Campbell and Schultz, Botolph House, 10 Eastcheap, London, E.C. [*Duke, London.* 1893.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java: (or care of R. Campbell, Slamat Cottage, Mount Vernon, Glasgow.)

1885. Capito, Charles Alfred Adolph, 12 Prince's Street, Hanover Square, London, W.; and 9 Belgrave Terrace, Lee, London, S.E.

1860. Carbutt, Edward Hamer, 19 Hyde Park Gardens, London, W.; and Nanhurst, Cranley, Guildford.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Burma State Railways, Inscin, Burma; care of Messrs. King King and Co., Bombay, India: (or care of Rev. J. H. Cardew, Wingfield Rectory, Trowbridge.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1887. Carlyle, Thomas, Lieutenant R.A., Inspector of Ordnance Machinery, Singapore: (or 72 Glyndon Road, Plumstead.)

1869. Carpmael, Frederick, 106 Croxted Road, West Dulwich, London, S.E.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, Chief Engineer, London and India Docks Joint Committee, Dock House, 109 Leadenhall Street, London, E.C.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Newbrough Lodge, Fourstones, R.S.O., Northumberland. [*Wardale, Gateshead.*]

1888. Carrick, Samuel Stewart, Superintendent Engineer, Shaw Savill and Albion Steamship Co., 34 Leadenhall Street, London, E.C.

1874. Carrington, William T. H., 72 Mark Lane, London, E.C.

1885. Carter, Herbert Fuller, Consulting Mechanical Engineer, Guanajuato, Mexico: (or care of H. Maynard Carter, 126 Wool Exchange, Basinghall Street, London, E.C.)

1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1891. Carter, William Charles, care of Messrs. A. H. Carr and Co., 5 Jeffrey Square, London, E.C.

1890. Carver, Henry Clifton, Messrs. Coates and Carver, 3 Cross Street, Manchester.

1888. Castle, Frank, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Caswell, Samuel John, 31 Sakai Machi, Kobe, Japan; and 35 Park Road, Crouch End, London, N.

1883. Cawley, George, 358 Strand, London, W.C.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1886. Chalmers, John Reid, 18 Hemingford Road, Barnsbury, London, N.

1884. Chamberlain, John, Charters Towers Gas Works, Charters Towers, Queensland: (or care of J. Chamberlain, 188 West Ferry Road, Millwall, Poplar, London, E.)

1890. Chandler, Noel, Cannock Chase Foundry and Engine Works, Hednesford. near Stafford.

1887. Chapman, Alfred Crawhall, 2 St. Nicholas' Buildings, Newcastle-on-Tyne.

1888. Chapman, Arthur, Messrs. Marillier and Edwards, 1 Hastings Street, Calcutta, India; Great Eastern Hotel, Calcutta, India: (or St. Andrew's Cottage, Bury St. Edmund's.)

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W. [*Tubalcain, London.*]; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1885. Chapman, John, Engineer and Manager, Windsor Corporation Water Works, Tangier Islands, Eton.

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1890. Chater, John Richard, Madras Railway, Madras, India.

1891. Chatterton, Alfred, Professor of Engineering, College of Engineering, Madras, India.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and High Lawn, Broad Oak Park, Worsley, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, The Terrace, H.M. Dockyard, Sheerness.

1877. Chisholm, John, General Manager, Messrs. A. and J. Stewart and Clydesdale, 41 Oswald Street, Glasgow; and 9 Corunna Street, Dumbarton Road, Glasgow.

1886. Chittenden, Edmund Barrow, Messrs. Chittenden Knight and Co., Sittingbourne; and Manor House, Offham, West Malling, near Maidstone.

1888. Chubb, Thomas Lyon, Locomotive Carriage and Wagon Superintendent, Ferro Carril del Oeste, Talleres Tolosa, Buenos Aires, Argentine Republic.

1880. Churchward, George Dundas, Locomotive Superintendent, China Railway Company, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough.)

1891. Clark, Augustus, Bowman's Heirs, Pernambuco, Brazil.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1889. Clark, Thomas Alexander, Superintendent of Workshops, George Heriot's Hospital School, Edinburgh.

1889. Clarke, Francis, Dane John Iron Works, Canterbury.

1885. Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1891. Clarkson, Thomas, Elm Tree Villa, Rosenau Road, Battersea, London, S.W.

1886. Clayton, Samuel, St. Thomas' Engine Works, Sunbridge Road, Bradford.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1890. Cleathero, Edward Thomas, Messrs. Cleathero and Nichols, Phœnix Works, Boleyn Road, Kingsland, London, N.; and 16 Tollington Place, London, N.

1890. Cleaver, Arthur, Engineer, Nottingham Laundry Co., Sherwood, near Nottingham; and Hornby House, Sherwood, near Nottingham.

1890. Cleland, William, Sheffield Testing Works, Blonk Street, Sheffield.

1871. Cleminson, James, Dashwood House, 9 New Broad Street, London, E.C. [*Catamarca, London.*]

1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln. [*Robey, Lincoln.*]

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, Engineers' Department, London County Council, Spring Gardens, London, S.W.

1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1889. Coey, Robert, Assistant Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1889. Colam, William Newby, Billiter Buildings, Billiter Street, London, E.C. [*Colam, London.*]

1884. Cole, Charles, Messrs. Cole Booth and Co., Vulcan Works, Dudley Hill, Bradford.

1878. Cole, John William, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.

1884. Collenette, Ralph, Bowling Iron Works, Bradford.

1884. Colquhoun, James, General Manager, Tredegar Iron Coal and Steel Works, Tredegar.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.

1889. Common, John Freeland Fergus, 4 Bute Crescent, Cardiff.

1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1888. Constantine, Ezekiel Grayson, 32 Victoria Street, Manchester. [*Constant, Manchester.*]

1886. Conyers, Sidney Ward, Railway Construction Branch, Public Works Department, Sydney, New South Wales.

1874. Conyers, William, National Mortgage and Agency Co. of New Zealand, Melbourne, Victoria.

1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helen's, Lancashire.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E. [*Patella, London.* 1140.]

1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.

1891. Cooper, Myles, 36 Victoria Street, Manchester.

1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness. [*Engine, Barrow-in-Furness.*]

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1878. Cornes, Cornelius, 6 Norfolk Crescent, Bath [*Stothert, Cornes, Bath.*]; and 76 Cannon Street, London, E.C. [*Stothert, Cornes, London.*]

1848. Corry, Edward, 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1883. Cotton, Henry Streatfeild, London Hydraulic Power Co., Palace Chambers, Bridge Street; Westminster, S.W.

1884. Cotton, John, 51 Alma Road, Birkdale, Southport.

1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.

1868. Coulson, William, 1 Pimlico, Durham.

1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.; and 76 Redcliffe Square, South Kensington, London, S.W.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1887. Crabbe, Alexander, 4 Hawkhill Place, Dundee.

1883. Crampton, George, care of T. Hillas Crampton, 100 Eaton Place, London, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1890. Craven, Thomas Edwin, 20 Victoria Chambers, South Parade, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1889. Cribb, Frederick James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1884. Crighton, John, Union Engineering Co., Pollard Street East, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1883. Croft, Henry, Chemauns, Vancouver Island.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1891. Crosland, Joseph, Messrs. Seebohm and Dieckstahl, Dannemora Steel Works, Sheffield; and Stanley Avenue, Birkdale, Southport.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Eirianfa, Llangollen.

1890. Cross, Robert James, Consulting Engineer, Great Western Steamship Co.; care of Messrs. Mark Whitwill and Son, Bristol.

1871. Crossley, William, 153 Queen Street, Glasgow. [*Crossley, Glasgow.* 584.]

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1886. Cryer, Thomas, Mechanical Engineering Department, Manchester Technical School, Princess Street, Manchester; and Urmston, near Manchester.

1889. Cullen, William Hart, Resident Engineer, The Aluminium Co., Oldbury, near Birmingham.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester. [*Curtius, Manchester.*]

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.; and 4 Westcombe Park, Blackheath, London, S.E.

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]; and 16 Great George Street, Westminster, S.W.

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India; and Cumbala Hill, Bombay, India.

1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]

1891. Daglish, Harry Bolton, Messrs. Robert Daglish and Co., St. Helen's Engine and Boiler Works, St. Helen's, Lancashire.

1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris; and 16 Rue des Chesneaux, Montmorency, Seine-et-Oise, France.

1890. Dalby, William Ernest, Engineering Department, The University, Cambridge.

1889. Dalgarno, James Robert, Danesford, Countess Wells Road, Mannofield, Aberdeen.

1881. D'Alton, Patrick Walter, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Fern Bank, Horsforth, Leeds.

1891. Daniels, Thomas, Messrs. Nasmyth Wilson and Co., Patricroft, Manchester.

1888. Darbishire, James Edward, 110 Cannon Street, London, E.C.

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W.

1884. Davidson, James Young, 13 Fairlawn Avenue, Acton Green, Chiswick, London, W.

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1884. Davies, Alfred Herbert, Eskell Chambers, Market Place, Nottingham.

1880. Davies, Charles Merson, Locomotive Carriage and Wagon Superintendent, Bengal-Nagpur Railway, Nagpur, Central Provinces, India; and Laurieville, Queen's Drive, Crosshill, Glasgow.

1885. Davies, Edward John Mines, 16 Camden Street, Oakley Square, London, N.W.

1891. Davies, John Hubert, P.O. Box 455, Johannesburg, Transvaal, South Africa.

1874. Davis, Alfred, 2 St. Ermin's Mansions, Westminster, S.W. [*Sivad, London.*]

1868. Davis, Henry Wheeler, 53 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 1 Arthur Street West, London, E.C.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1877. Davison, John Walter, Park Cottage, South Hill Road, Milton, near Gravesend.

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield. [*Motor, Sheffield.*]

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, Staffa Lodge, South Park Hill Road, Croydon.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1875. Dawson, Edward, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1890. Day, George Cameron, Messrs. Day Summers and Co., Northam Iron Works, Southampton.

1886. Dayson, William Ogden, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, Victoria Mansions, 32 Victoria Street, Westminster, S.W.

1880. Deacon, Richard William, Messrs. Samuel Fisher and Co., Nile Foundry, Birmingham; and 19 Clarendon Road, Edgbaston, Birmingham.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1887. Deas, James, Clyde Navigation, Glasgow.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine et Oise, France. [*Decauville, Corbeil.*]

1890. Deeley, Richard Mountford, Locomotive Department, Midland Railway, Derby; and 10 Charnwood Street, Derby.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1889. Defries, Wolf, Messrs. Defries and Sons, 147 Houndsditch, London, E. [*Defries, London.*]

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1882. Denison, Samuel, Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1888. Dent, Charles Hastings, Locomotive Department, London and North Western Railway, Preston.

1883. Dick, Frank Wesley, Palmers Shipbuilding and Iron Works, Jarrow.

1891. Dick, John Norman, Government Engineer Surveyor, Penang, Straits Settlements.

1890. Dickinson, Alfred, Engineer, South Staffordshire Tramways, Darlaston, Wednesbury.

1891. Dickinson, Douglas Holt, 208 Casilla del Correo, Monte Video, Uruguay: (or care of I. G. Dickinson, National Provincial Bank of England, Newcastle-on-Tyne.)

1891. Dickinson, James Clark, Palmer's Hill Engine Works, Sunderland.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1888. Dickson, George Manners, Assistant Engineer, Calcutta Water Works, Municipal Office, Calcutta, India.

1886. Dixon, Robert, Messrs. Dixon and Corbitt, Teams Hemp and Wire Rope Works, Gateshead. [*Dixon, Gateshead.*]

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.*]

1887. Dixon, William Basil, Earle's Shipbuilding and Engineering Works, Hull.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, Suiker Fabrick, Kalibayor, Banjoemas, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1889. Dolby, Ernest Richard, 8 Prince's Street, Westminster, S.W.

1880. Donald, James, Messrs. James Fisher and Sons, Fisher's Buildings, Barrow-in-Furness.

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1884. Donnelly, John, 45 Brockley Road, London, S.E.

1891. Donovan, Edward Wynne, Brush Electrical Engineering Co., 112 Belvedere Road, Lambeth, London, S.E.; and 21 Lancaster Park, Richmond, Surrey.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, F.R.S., Trinity House, London, E.C. [2242.]; and Stella House, Dulwich, London, S.E.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1891. Douglass, William James, Messrs. Douglass Brothers, Globe Iron Works, Blaydon-on-Tyne, R.S.O., County Durham.

1887. Douglass, William Tregarthen, 17 Victoria Street, Westminster, S.W.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hatfield House, Hatfield, near Doncaster.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W. [*Gaseous, London.*]

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1890. Drewet, Tom, Government Senior Inspector of Steam Boilers, Town Custom House, Bombay, India.

1886. Drummond, Dugald, Locomotive Superintendent, Caledonian Railway, St. Rollox Works, Glasgow.

1889. Drummond, Richard Oliver Gardner, De Beer's Diamond Mining Co., Kimberley, South Africa.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 182 Lewisham Road, London, S.E. [*Duckham, London.*]

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Doucine, London.*]; and Kilmux, Leven.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Charlcombe Grove, Lansdown, Bath.

1890. Dunn, Hugh Shaw, Engineer, Caprington Collieries, Kilmarnock.

1885. Durham, Frederick William, 27 Leadenhall Street, London, E.C. [*Oilring, London.*]; and Glenham Lodge, New Barnet.

1886. Duvall, Charles Anthony, Lucigen Light Co., Page Street, Westminster, S.W.

1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1887. Edlin, Herbert William, Poste Restante, Cape Town, Cape Colony: (or The Limes, Ellerton Road, Surbiton, R. O., Kingston-on-Thames.)

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1871. Edwards, Edgar James, 12 Dartmouth Street, Westminster, S.W.; and 42 Rye Hill Park, Peckham, London, S.E.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1888. Ellery, Henry George, 7 Fernbank Road, Redland, Bristol.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses. [*Elliot Company, London.*]

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]

1869. Elliott, Henry Worton, Selly Oak Works, near Birmingham. [*Elmeco, Birmingham.*]

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 6 Grosvenor Place, Jesmond, Newcastle-on-Tyne. [*Robey, Newcastle-on-Tyne.*]

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India; and 91 King Henry's Road, London, N.W.

1875. Elwell, Thomas, 223 Avenue de Paris, Plaine St. Denis, Seine, France.

1878. Elwin, Charles, London County Council, Spring Gardens, London, S.W.

1889. Emett, George Henry Hawkins, Hope Foundry, Dewsbury. [*Emett, Dewsbury.*]

1890. English, Lt.-Colonel Thomas, Palmer's Ordnance Works, Jarrow.

1885. Errington, William, Salisbury Buildings, Bourke Street, Melbourne, Victoria.

1891. Esson, David Duncan, MacIvor's White Lead Co., Candor Works, Northfleet, S.O., Kent.

1890. Esson, John, Messrs. Blaikie Brothers, Footdee Iron Works, Aberdeen.

1889. Etches, Harry, 10 Langney Road, Eastbourne.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Messrs. Bolckow Vaughan and Co., Cleveland Iron and Steel Works, South Bank, R.S.O., Yorkshire.

1888. Evans, Joseph, Culwell Foundry, Wolverhampton.

1885. Evans, Richard Kendall, Engineering Works, Sandiacre, near Nottingham; and Whiston Grange, Rotherham.

1887. Everard, John Breedon, 6 Millstone Lane, Leicester.

1887. Everitt, Nevill Henry, Patent Shaft Works, Wednesbury; and Knowle Hall, Warwickshire.

1881. Ewen, Thomas Buttwell, Messrs. Ewen and Mitton, Smithfield Works, Sherlock Street, Birmingham.

1891. Ewing, James Alfred, F.R.S., Professor of Mechanism and Applied Mechanics, Engineering Department, The University, Cambridge; and Langdale Lodge, Cambridge.

1890. Exton, George Gaskell, Messrs. Chubb and Son, 128 Queen Victoria Street, London, E.C.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and care of Messrs. F. A. Robinson and Co., 69 Cornhill, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1884. Fearfield, John Piggin, Lace Machine Works, Stapleford, near Nottingham; and The Ferns, Stapleford, near Nottingham. [*Fearfield, Nottingham.*]

1888. Featherstone, William Bromley, 4 Princes Square, Kennington Park, London, S.E.

1882. Feeny, Victor Isidore, 60 Queen Victoria Street, London, E.C. [*Victor Feeny, London.*]

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1877. Fenton, James, 4 Victoria Road, Kensington, London, W.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E. [*Clennell, London.*]

1870. Ferguson, Henry Tanner, Wolleigh, Bovey Tracey, near Newton Abbot.

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1866. Fiddes, Walter, Clapton Villa, Belgrave Road, Tyndall's Park, Bristol.

1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1888. Field, Howard, Messrs. John Bell and Son, 118A Southwark Street, London, S.E.; and Hillcote, Buckhurst Hill, S.O., Essex.

1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1891. Finlayson, Finlay, Messrs. Miller and Co., Vulcan Foundry, Coatbridge.

1891. Firth, George Henry, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1887. Firth, William, Water Lane, Leeds.

1888. Fischer, Gustave Joseph, Tramway Construction Branch, Public Works Department, Beresford Chambers, Castlereagh Street, Sydney, New South Wales.

1889. Fisher, Henry Bedwell, Locomotive Works, London Brighton and South Coast Railway, Brighton.

1884. Fisher, Henry Oakden, Engineer, Taff Vale Railway, Cardiff.

1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C. [2283.]

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users', Manchester.*]

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.

1886. Folger, William Mayhew, Commander, United States Navy, Bureau of Ordnance, Naval Department, Washington, D.C., United States.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Bombay.

1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.

1888. Forster, Edward John, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1882. Forsyth, Robert Alexander, Courtway, Gold Tops, Newport, Monmouthshire.

1889. Foster, Ernest Howard, Messrs. Henry R. Worthington, 86 Liberty Street, New York, United States.

1886. Foster, Frederick, Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N. [*Drinks, London.* 306.]

1889. Foster, Herbert Anderton (*Life Member*), Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1888. Foster, James, Lily Bank, St. Andrew's Drive, Pollokshields, Glasgow.

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Superintendent Marine Engineer, 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1885. Fourny, Hector Foster, French Chambers, Queen's Dock-Side, Hull. [*Veritas, Hull.*]

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, Bart., K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1885. Fowler, William Henry, 6 Victoria Station Approach, Manchester; and The Poplars, New Moston, near Manchester.

1866. Fox, Sir Douglas, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1882. Fox, William, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1888. Francken, William Augustus, Public Works Department, India; care of Messrs. Grindlay Groom and Co., Bombay, India; and care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Goldsbrough Mort and Co., 149 Leadenhall Street, London, E.C.)

1877. Fraser, John Hazell, 110 Cannon Street, London, E.C.

1888. Frenzel, Arthur Benjamin, 93 Liberty Street, New York, United States.

1891. Frier, John Drummond, Veysurpaudi, Madras, India.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Barnsley Road, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1891. Fuller, Charles Frederick, 171 Queen Victoria Street, London, E.C.

1884. Furness, Edward, Messrs. Pontifex and Wood, Shoe Lane, London, E.C.; and Knollcroft, Knoll Road, Bexley, S.O., Kent.

1890. Gadd, William, Assistant Locomotive Carriage and Wagon Superintendent, Waterford and Limerick Railway, Limerick.

1887. Gaertner, Ernst, I. Fichtegasse 5, Vienna, Austria.

1866. Galloway, Charles John, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. Galton, Sir Douglas, K.C.B., D.C.L., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1884. Ganga Ram, Lala, Executive Engineer, Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Thomas Wilson and Co., 24 Rood Lane, London, E.C.)

1891. Garrard, Charles Riley, Abingdon Works, Bath Street, Birmingham.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1888. Gaze, Edward Henry James, 4 Victoria Drive, Mount Florida, Glasgow.

1888. Geddes, Christopher, Leeds Forge, Leeds.

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]

1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.; and 30 South Street, Greenwich, London, S.E.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1883. Gilchrist, Percy Carlyle, F.R.S. (*Life Member*), Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London*]; and Frognal Bank, Finchley New Road, Hampstead, London, N.W.

1856. Gilkes, Edgar, Westholme, Grange-over-Sands, viâ Carnforth, Lancashire.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1889. Gill, Frederick Henry, 20 Bucklersbury, London, E.C.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1884. Girdlestone, John Ward, 2 Nottingham Place, London, W.

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1887. Gledhill, Manassah, Sir Joseph Whitworth and Co., Openshaw, Manchester.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.

1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland: (or care of Messrs. James McEwan and Co., 27 Lombard Street, London, E.C.)

1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester. [*Goldsworthy, Manchester.*]

1867. Gooch, William Frederick, Vulcan Foundry, Newton-le-Willows, Lancashire.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1884. Goodger, Walter William, Messrs. George Fletcher and Co., Masson and Atlas Works, Litchurch, Derby.

1890. Goodman, John, Professor of Engineering, Yorkshire College, Leeds.

1885. Goodwin, Arnold, Jun., 56 Sumner Street, Southwark, London, S.E.

1889. Goold, William Tom, 39 Queen Victoria Street, London, E.C.; and 18 The Hawthorns, Finchley, London, N.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 118 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1875. Gordon, Robert, 6 Pilmour Place, St. Andrews.

1888. Gore, Arthur Saunders, Sherborne Metal Works, Sherborne Street, Birmingham.

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1887. Gourlay, Charles Gershom, Messrs. Gourlay Brothers and Co., Dundee Foundry, Dundee.

1890. Grace, Robert William, Messrs. Washburn and Moen, Worcester, Massachusetts, United States.

1878. Grafton, Alexander, Vulcan Works, Bedford. [*Grafton, Bedford.*]

1891. Gray, George Macfarlane (*Life Member*), Imperial Chinese Customs, Hong Kong, China.

1865. Gray, John Macfarlane, Chief Examiner of Engineers, Marine Department, Board of Trade, St. Katharine Dock House, Tower Hill, London, E.; and 1 Claremont Road, Forest Gate, London, E. [*Yarg, London.*]

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, 15 Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., M.P., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1888. Green, Henry Joseph Kersting, Engineer, Bishnauth Tea Co., Charalli Post Office, Assam, Bengal.

1871. Greener, John Henry, 15 Walbrook, London, E.C.

1890. Greening, William Alfred, 88 Bishopsgate Street Within, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Birmingham Small Arms and Metal Co., Adderley Park Works, Birmingham.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1879. Grenville, Robert Neville, Butleigh Court, Glastonbury.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester. [*Brake, Manchester.*]

1883. Grew, Frederick, care of F. W. Grew, Victoria Iron Works, Sowerby Bridge.

1871. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1884. Griffiths, James E., Messrs. Griffiths and Wills, Merchants' Exchange, Cardiff. [*Griffwill, Cardiff.*]

1873. Griffiths, John Alfred, Charters Towers, Queensland.

1889. Grimshaw, James Walter, Resident Engineer, Harbours and Rivers Department, Sydney, New South Wales; and Australian Club, Sydney, New South Wales.

1891. Groom, Richard Alfred, Shropshire Works, Wellington, Salop.

1879. Grose, Arthur, Messrs. Grose Norman and Co., Reliance Works, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham. [*Cowen, Nottingham.* 87.]

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1886. Guy, Charles Williams, Laurel Bank, Penge, London, S.E.

1870. Gwynne, James Eglinton Anderson (*Life Member*), Essex Street Works, Strand, London, W.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.; and 89 Cannon Street, London, E.C.

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield. [*Hadfield, Sheffield.*]

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 111 Federal Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1879. Hall, John Francis, Norbury, Pittsmoor, Sheffield.

1881. Hall, John Percy, Managing Director, Messrs. John Penn and Sons, Greenwich, London, S.E.

1882. Hall, John Willim, Ivy House, Bilston.

1890. Hall, Oscar Standring, Messrs. Robert Hall and Sons, Hope Foundry, Bury.

1874. Hall, Thomas Bernard, 119 Colmore Row, Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, Messrs. Takata and Co., Ginza San Chome 18, Banchi, Tokio, Japan: and 88 Bishopsgate Street Within, London, E.C.

1889. Hall-Brown, Ebenezer, Messrs. Thomas Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1880. Hallett, John Harry, 115 Bute Docks, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* 3075, care of Victoria Chambers Co.]

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Jundiahy, São Paulo, Brazil (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1886. Hanbury, John James, Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1870. Hannah, Joseph Edward, Water Works, Winnipeg, Manitoba, Canada.

1888. Harada, Torazo, Superintending Engineer, Osaka Shipping Co., Osaka, Japan.

1891. Harcourt, Otto Simon Henry, Clarence Iron Works, Leeds.

1883. Harding, Thomas Walter, Tower Works, Leeds.

1874. Harding, William Bishop, Ixker. Rakosuteza 5 ik. sz., 1sö. Emelet, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1887. Hargraves, Richard, Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1884. Harker, Harold Hayes, Locomotive Superintendent, Minas and Rio Railway, Cruzeiro, Rio de Janeiro, Brazil: (or care of Jesse T. Curtis, Hill Street, Poole.)

1888. Harker, William, Messrs. Richard Schram and Co., 17A Great George Street, Westminster, S.W.

1888. Harland, Sir Edward James, Bart., M.P., Messrs. Harland and Wolff, Belfast; Glenarm Castle, County Antrim; and Baroda House, Kensington Palace Gardens, London, W.

1873. Harman, Harry Jones, 36 Gaisford Street, Kentish Town, London, N.W.

1891. Harris, Gordon, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.

1879. Harris, Henry Graham, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.

1885. Harris, John Henry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C. [*Tuncharp, London.*]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1888. Harrison, George, 21 Hillsboro Road, East Dulwich, London, S.E.

1889. Harrison, Gilbert Harwood, Lieutenant R.E., Assistant Inspector of Gun Carriages, Royal Arsenal, Woolwich.

1885. Harrison, Joseph, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Harrison, Joseph Hutchinson, York House, Malvern Link, Malvern.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 139 Queen Victoria Street, London, E.C.; and 22 Granville Villas, Earlsfield Road, Wandsworth, London, S.W.

1890. Harrison, William Robert, Manager, Hull Cart and Wagon Co., Newington Iron Works, Hull.

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.)

1882. Hart, Norman, London Chatham and Dover Railway, Locomotive (Marine) Department, Dover.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1886. Harvey, John Boyd, The Liverpool Nitrate Co., Oficina Ramirez, Iquique, Chile: (or care of Robert Harvey, 1 Palace Gate, London, W.)

1883. Harvey, Robert, 1 Palace Gate, London, W.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1881. Haslam, Sir Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, Waterside, Ferry Road, Teddington, S.O., Middlesex.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1891. Hawksley, George William, Brightside Boiler and Engine Works, Savile Street East, Sheffield. [*Hawksley, Sheffield.* 337.]

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, Messrs. Francis Morton and Co., Hamilton Iron Works, Garston, Liverpool.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1885. Head, Archibald Potter, Queen's Square, Middlesbrough.

1888. Head, Harold Ellershaw, 24 Auriol Road, West Kensington, London, W.

1869. Head, Jeremiah, Queen's Square, Middlesbrough [*Head, Middlesbrough.*]; and 26 Lombard Street, London, E.C.

1873. Headly, Lawrance, Exchange Iron Foundry and Implement Works, Corn Exchange Street, Cambridge; and Yorke House, Newmarket Road, Cambridge. [*Vanes, Cambridge.*]

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1890. Heap, Ray Douglas Theodore, Messrs. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and 35 Addison Gardens, Kensington, London, W.

1872. Heap, William, 9 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]

1889. Heath, George Wilson, Messrs. Heath and Co., Observatory Works, Crayford, Kent.

1888. Heatly, Harry, 30 Strand, Calcutta, India.

1875. Heenan, Richard Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester; and The Manor House, Wilmslow, near Manchester. [*Spherical, Newton Heath.*]

1879. Hele-Shaw, Henry Selby, Professor of Engineering, University College, Liverpool.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1891. Henderson, Thomas, 6 and 8 Trueman Street, Liverpool.

1883. Henderson, William, Perth Road, Stanley, R.S.O., Perthshire.

1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay; and 3 Beckett Terrace, Uxbridge.

1888. Henning, Gustavus Charles, 726 Temple Court, 5 Beekman Street, New York, United States.

1879. Henriques, Cecil Quixam, 113 Cannon Street, London, E.C.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1891. Hepburn, Thomas, Chief Engineer, Gunpowder Factory, Kirkee, Poona, India.

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1884. Herna, Arthur Henry, 69 Victoria Street, Westminster, S.W.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1887. Hibbert, George, Hibbert's Works, Bank Road, Gateshead.

1871. Hick, John, Mytton Hall, Whalley, near Blackburn.

1885. Hicken, Thomas, care of Messrs. Alexander Shanks, Hijos and Co., 416 Calle Alsina, Buenos Aires, Argentine Republic: (or care of John Hicken, Bourton, near Rugby.)

1864. Hide, Thomas Comings, 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1889. Hill, Arthur Ripley, Messrs. Hill Brothers, Nevins Foundry, Hunslet, Leeds.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1890. Hiller, Edward George, Chief Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1882. Hiller, Henry, Consulting Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester; and Athelney, Stanley Road, Alexandra Park, Manchester.

1873. Hilton, Franklin, General Works Manager, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and South Bank, R.S.O., Yorkshire.

1887. Hindson, William, Messrs. J. Abbot and Co., Park Works, Gateshead.

1891. Hodge, Arthur, Trewirgie, Redruth.

1891. Hodges, Frank Grattidge, Carriage and Wagon Works, Midland Railway, Derby.

1870. Hodges, Petronius, 142 Burngreave Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1889. Hodgson, George Herbert, Thornton Road, Bradford.

1891. Hogarth, Thomas Oswald, Great Western Railway Works, Swindon.

1889. Hoggins, Alfred Farquharson, Messrs. Henry De Jersey and Co., 1 Tokenhouse Buildings, Bank of England, London, E.C.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1884. Holland, Calvert Bernard, General Manager, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1886. Hollis, Charles William, Messrs. Ketton and Hollis, Meadow Tool Works, Mayfield Grove, Nottingham.

1885. Hollis, Henry William, Thornville House, Darlington.

1891. Holman, Hugh Wilson, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1883. Holroyd, John, Tomlinson Street, Hulme, Manchester. [*Knit, Manchester.*]

1885. Holroyd, John Herbert, West's Patent Press Company, Etawah, N.W. Provinces, India.

1863. Holt, Francis, Locomotive Department, Midland Railway, Derby.

1873. Holt, Henry Percy, The Cedars, Didsbury, Manchester.

1890. Holt, Robert, Lecturer in Engineering, Walker Engineering Laboratories, Brownlow Hill, Liverpool.

1890. Holt, William Procter, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1888. Homan, Harold, Messrs. Homan and Rodgers, 10 Marsden Street, Manchester. [*Namoh, Manchester.* 637.]

1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.

1890. Hooker, Benjamin, Pear Tree Court, Farringdon Road, London, E.C.

1883. Hooton, William, Continental Lace-Machine Works, Great Eastern Street, Nottingham.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham; and 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1890. Hopper, Allan, Messrs. William Hopper and Co., Moscow, Russia.

1890. Hopper, James Russell, Messrs. William Hopper and Co., Moscow, Russia.

1889. Hopwood, John, Locomotive Superintendent, Argentine Great Western Railway, Mendoza, Argentine Republic.

1889. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1889. Horsfield, Cooper, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1891. Horsfield, Ralph, Messrs. Kirk and Horsfield, Chapel-en-le-Frith, near Stockport.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, 4 Cedars Road, Clapham Common, London, S.W.

1886. Hosgood, John Howell, Locomotive and Hydraulic Superintendent, Barry Dock and Railways, Barry, near Cardiff.

1875. Hosgood, Thomas Hopkin, 26 Brunswick Street, Swansea.

1889. Hosken, Richard, Severn Tunnel Works, Sudbrook, near Chepstow.

1873. Hoskin, Richard, 8 Norfolk Street, Sheffield.

1888. Hosking, Thomas, Messrs. T. and J. Hosking, Dockhead Iron Works, 53 Parker's Row, Bermondsey, London, S.E.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1889. Houghton, Thomas Harry, Water Works, Crown Street, Sydney, New South Wales: (or care of Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.)

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1891. How, William Field, Mutual Life Buildings, George Street, Sydney, New South Wales. [*Alaska, Sydney.*]

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1879. Howard, James Harold, Britannia Iron Works, Bedford; and Kempston Grange, Bedford.

1882. Howard, John William, 78 Queen Victoria Street, London, E.C.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1882. Howl, Edmund, Messrs. Lee Howl and Co, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1891. Hoy, Henry Albert, Locomotive Works, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1884. Hoyle, Frank Edward, care of E. Irving, 14 Bryanstone Road, St. Michaels Liverpool.

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1891. Hubback, Charles Arbuthnot, 9 Church Crescent, St. Albans.

1882. Hudson, John George, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton; and Glenholme, Bromley Cross, Bolton.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1881. Hughes, Edward William Mackenzie, Locomotive and Carriage Superintendent, East Coast State Railway, Waltair, Vizagapatam, Madras Presidency, India: (or Ericstane, Helensburgh.)

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1889. Hughes, John, Messrs. Hughes and Lancaster, City Road, Chester.

1871. Hughes, Joseph, Kingston, Wareham.

1891. Hughes, Robert M., Engineering Department, University College, Liverpool.

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1890. Humphries, Edward Thomas, Messrs. Edward Humphries and Co., Atlas Iron Works, Pershore.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, Albion Iron Works, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Egerton Mount, Heaton Chapel, R.O., Stockport.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1889. Hunter, Charles Lafayette, Engineer, Bute Docks, Cardiff.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1888. Huxley, George, 20 Mount Street, Manchester.

1885. Hyland, John Frank, Railway Contractor, São Carlos do Pinhal, Estado de São Paulo, Brazil: (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, Assistant Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1888. Ingleby, Joseph, 20 Mount Street, Manchester.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.

1883. Instone, Thomas, 22 Leadenhall Buildings, Leadenhall Street, London, E.C.

1889. Irvine, William Charles, Messrs. Irvine and Co., Harbour Dockyard, West Hartlepool.

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1887. Ivatts, Lionel Edward, 14 Henao 1o. Yz., Bilbao, Spain.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and Woodgreen, Wednesbury.

1859. Jackson, Matthew Murray, 47 Norton Road, West Brighton, Brighton; and care of Messrs. Howard and Pitcairn, 155 Fenchurch Street, London, E.C.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1873. Jackson, Samuel, C.I.E., care of E. Jackson, Beltwood, Ranmoor, Sheffield.

1886. Jackson, Thomas, 131 Hyde Park Road, Headingley, Leeds.

1889. Jackson, William, Thorn Grove, Mannofield, Aberdeen.

1872. Jackson, William Francis, Sterndale House, Litton, near Stockport.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1889. James, Charles William, New York Oxygen Co., 80 Broadway, New York, United States.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1889. James, Reginald William, 1 Queen Victoria Street, London, E.C.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1888. Jaques, Lieut. William Henry, Secretary to Ordnance Committee, United States; and Bethlehem Iron Works, Bethlehem, Pa., United States.

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1877. Jeffreys, Edward Homer, Hawkhills, Chapel Allerton, Leeds.

1884. Jenkins, Alfred, Wharncliffe, Victoria Road, Penarth.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1889. Jessop, George, London and Leicester Steam-Crane and Engine Works, Leicester.

1886. Jewell, Henry William, Messrs. Jewell and Son, City Foundry, Winchester.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 9 Upper Northgate Street, Chester.

1882. Johnson, Charles Malcolm, H.M.S. "Hibernia," Malta.

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1890. Johnson, John William, care of Baron Knoop, Grande Loubianka, Moscow, Russia.

1891. Johnson, Lacey Robert, Master Mechanic, Pacific Division, Canadian Pacific Railway, Vancouver, British Columbia.

1888. Johnson, Lawrence Potter, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1891. Johnston, Andrew, Bank Buildings, Hong Kong, China.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. John, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1891. Jones, Charles Frederick, Messrs. Greaves Cotton and Co., Empress Mill, Delisle Road, Parel, Bombay, India.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Kirkstall, Aldridge Road, Perry Barr, Birmingham.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, District Locomotive Superintendent, North Western Railway, Multan, Punjaub, India: (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1890. Jones, Morlais Glasfryn, 6 Delahay Street, Westminster, S.W.

1882. Jones, Samuel Gilbert, Hatherley Court, Gloucester.

1887. Jones, Thomas, Central Board School, Deansgate, Manchester.

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: 3 Northumberland Avenue, Putney, London, S.W.: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1891. Jordan, Henry George, Jun., Technical School of the Whitworth Institute, Manchester.

1880. Joy, David, 8 Victoria Chambers, 15 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1891. Judd, Joseph Henry, Technical and Manual Instruction School, York Place, Brighton.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 2504.]

1889. Kanthack, Ralph, Sub-Manager, Carl Zeiss' Optical Works, Jena, Germany.

1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.

1882. Keeling, Herbert Howard, Merlewood, Eltham.

1869. Keen, Arthur, London Works, near Birmingham. [*Globe, Birmingham.*]

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Westbromwich.

1867. Kellett, John, Clayton Street, Wigan.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.

1879. Kennedy, Professor Alexander Blackie William, F.R.S., 19 Little Queen Street, Westminster, S.W. [*Kinematic, London.*]

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Parkhill, Wetherby.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1888. Kershaw, Frederic, Evans y Livock, 228 Calle Piedad, Buenos Aires, Argentine Republic.

1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1890. Key, George Andrew, General Manager, Wallsend Pontoon Works, Bute Docks, Cardiff.

1885. Keydell, Amandus Edmund, Lloyd's Register of Shipping, Dundee.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic: (or care of J. R. H. Keyworth, 25 Park Road South, Birkenhead.)

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1889. Kirby, Frank Eugene, Constructing Engineer, Detroit Dry Dock Co., Detroit, Michigan, United States.

1872. Kirk, Alexander Carnegie, LL.D., Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Commissioner of Customs, Kowloon, Hong Kong, China: (or Melita Cottage, Denny.)

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1889. Knap, Conrad, 11 Queen Victoria Street, London, E.C.

1891. Knight, Bertrand Thornton, Consulting Engineer to the British North Borneo Government, Sandakan, British North Borneo; and 3 Westfield Road, Surbiton.

1886. Knight, Charles Albert, Babcock and Wilcox Boiler Co., 107 Hope Street, Glasgow.

1890. Knight, James Percy, Messrs. A. W. Robertson and Co., Custom House Engine Works, Victoria Docks, London, E.

1889. Knox, James, Civil and Mechanical Engineer, Auckland, New Zealand: (or care of E. D. Knox, 53 Belsize Park Gardens, South Hampstead, London, N.W.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead. [*Laird, Birkenhead.* 4003.]

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead. [*Laird, Birkenhead.* 4003.]

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1878. Lambourn, Thomas William, Naughton Hall, near Bildeston, S.O., Suffolk.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of T. C. Langdon, Tamar Terrace, Launceston.)

1881. Lange, Frederick Montague Townshend, 21 Rue Wissocq, Boulogne-sur-mer, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, 33 Chester Terrace, Regent's Park, London, N.W.

1879. Lapage, Richard Herbert, Elmwood, Surbiton.

1890. Last, Arthur John, Oulton, Abbeville Road, Balham, London, S.W.

1888. Latham, Baldwin, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.

1890. Laurie, Leonard George, Mill Parade, Newport, Monmouthshire.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Layborn Patterson and Co., Dutton Street, Liverpool.

1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1889. Leaf, Henry Meredith, Messrs. Crompton and Co., Mansion House Buildings, Queen Victoria Street, London, E.C.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1890. Ledingham, John Machray, Royal Laboratory, Royal Arsenal, Woolwich.

1886. Lee, Charles Eyre, 18 Newhall Street, Birmingham.

1887. Lee, Cuthbert Ridley, Messrs. J. Coates and Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1862. Lee, J. C. Frank, 9 Park Crescent, Portland Place, London, W.

1890. Lee, Samuel Edward, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 15 George Street, Mansion House, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1889. Legros, Lucien Alphonse, 57 Brook Green, Hammersmith, London, W.

1883. Lennox, John, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1858. Leslie, Andrew, Coxlodge Hall, Newcastle-on-Tyne.

1888. Leslie, Sir Bradford, K.C.I.E., Tarrangower, Willesden Lane, Brondesbury, London, N.W.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

1888. Letchford, Joseph, Manager, Messrs. David Munro and Co., Stuart Street, Melbourne, Victoria; care of Richard Speight, Glenroy Park, Hampton Street, Middle Brighton, Melbourne, Victoria: (or care of James Letchford, 370 Wandsworth Road, London, S.W.)

1878. Lewis, Gilbert, 37 Monton Street, Moss Side, Manchester.

1884. Lewis, Henry Watkin, Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1887. Lewis, Rowland Watkin, Messrs. Edwin Lewis and Sons, Britannia Boiler Tube Works, Wolverhampton.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1887. Lindsay, Joseph, Messrs. Urquhart Lindsay and Co., Blackness Foundry, Dundee.

1891. Lindsay, William Robertson, Messrs. W. B. Thompson and Co., Lilybank Engine Works, Dundee.

1890. Lineham, Wilfrid James, Professor of Engineering and Mechanical Science, The Goldsmiths' Institute, New Cross, London, S.E.; and Jesmond, Leyland Road, Lee, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.; and 3 St. John's Park, Blackheath, London, S.E.

1885. Lister, Frank, Messrs. Lister and Co., Beecheliffe, Keighley; and Oaklands, Keighley.

1890. Lister, Robert Ramsbottom, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1890. Livens, Frederick Howard, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1867. Livesey, James, 29, 30 and 31 Broad Street Avenue, London, E.C.

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1867. Lloyd, Charles, National Conservative Club, 9 Pall Mall, London, S.W.

1871. Lloyd, Francis Henry, James Bridge Steel Works, near Wednesbury [*Steel, Wednesbury*]; and Stowe Hill, Lichfield.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1890. Locke, Arthur Guy Neville, 12 Dartmouth Street, Westminster, S.W.

1879. Lockhart, William Stronach, 67 Granville Park, Blackheath, London, S.E.

1881. Lockyer, Norman Joseph, care of Sir A. M. Rendel, 8 Great George Street, Westminster, S.W.

1884. Logan, Andrew Linton, Vulcan Foundry, Newton-le-Willows, Lancashire.

1890. Logan, John Walker, Messrs. Richard Hornsby and Sons, P. O. Box 216, Johannesburg, Transvaal, South Africa; and care of William Weatherley, 51 Newlands, Lincoln.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, 2 Charleville Road, Park Road, Dublin.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1888. Low, David Allan, Lecturer on Engineering, The People's Palace Technical Schools, Mile End Road, London, E.

1861. Low, George, Bishop's Hill Cottage, Ipswich.

1885. Low, Robert, Powis Lodge, Vicarage Park, Plumstead.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, General Manager, Barry Graving Dock and Engineering Co., Exchange Buildings, Cardiff. [*Bardock, Cardiff.*]

1891. Lowdon, Thomas, Kingsland Crescent, Barry Docks, B.O., near Cardiff.

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1873. Lucas, Arthur, 27 Bruton Street, New Bond Street, London, W.

1889. Lucy, Arthur John, Messrs. Turner Morrison and Co., Sugar Works Cossipore, Calcutta, India.

1886. Lucy, William Theodore, care of Frank Hudson, Central Uruguay Railway, Monte Video, Uruguay: English Club, Monte Video, Uruguay: (or Thornleigh, Woodstock Road, Oxford.)

1889. Lundon, Robert, Engineer's Department, Rosstown Junction Railway and Property Co., Bourke Street East, Melbourne, Victoria; and 66 Elizabeth Street, Melbourne, Victoria.

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1887. Lupton, Kenneth, 6 Gordon Terrace, Cope Street, Coventry.

1878. Lynde, James Henry, Buckland, Ashton-on-Mersey, near Manchester.

1889. Macallan, George, Works Manager, Great Eastern Railway, Stratford Works, London, E.

1890. Macan, Richard Thompson, Dawlish House, Willesden, London, N.W.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1890. MacBrair, William Maxwell, 26 Parkers Road, Sheffield.

1884. MacCarthy, Samuel, Messrs. Lloyd and Lloyd, 90 Cannon Street, London, E.C.; and 18 Adelaide Road, Brockley, London, S.E.

1877. MacColl, Hector, Messrs. MacIlwaine and MacColl, Ulster Iron Works, Belfast.

1879. Macdonald, Augustus Van Zundt, Locomotive Engineer, Addington, Christchurch, New Zealand.

1889. Macdonald, James Alexander, Broad Oaks Iron Works, Chesterfield.

1890. Mackay, Joseph, Bangkok Dock Co., Bangkok, Siam: (or care of Messrs. John Birch and Co., 10 Queen Street Place, London, E.C.) [*Mackay, Bangkok.*]

1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 40 Chancery Lane, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1875. Maclagan, Robert, care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.

1889. MacLay, Alexander, Professor of Mechanical Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1888. Macleod, Arthur William, Schwebo Mining Syndicate, Kyouk Myoung Post Office, Upper Burmah.

1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokyo, Japan.

1865. Macnee, Daniel, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W. [*Macnee, London.*]; and Rotherham.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*James Maginnis, London;* and *Offsett, London.*]

1891. Mahon, Reginald Henry, Captain R.A., Superintendent H.M. Shell Factory, Cossipore, Calcutta, India.

1873. Mair-Rumley, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1884. Mais, Henry Coathupe, 61 Queen Street, Melbourne, Victoria.

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1891. Manisty, Edward, Dundalk Iron Works, Dundalk, Ireland; and Oaklands, Bromborough, near Birkenhead.

1888. Mano, Bunji, Professor of Mechanical Engineering, Imperial University, Tokyo, Japan.

1875. Mansergh, James, 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W.

1891. Manson, James, Locomotive Superintendent, Glasgow and South Western Railway, Kilmarnock.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1878. Marié, Georges, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1891. Marks, Edward Charles Robert, 13 Temple Street, Birmingham.

1888. Marks, George Croydon, 13 Temple Street, Birmingham. [*Pumps, Birmingham.*]

1884. Marquand, Augustus John, Pierhead Chambers, Cardiff. [*Electranode, Cardiff.*]

1887. Marriott, William, Engineer and Locomotive Superintendent, Eastern and Midlands Railway, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Rev. Alfred (*Life Member*), The Vicarage, Feckenham, Redditch.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1890. Marshall, Frank Herbert, Ormesby Iron Works, Middlesbrough.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Messrs. Chance Brothers and Co., Glass Works, near Birmingham; and Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Pedmore, Stourbridge. [*Marten, Stourbridge.* 8504.]

1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1878. Martin, Henry, 8 East Park Terrace, Southampton.

1888. Martin, Henry James, Tresleigh House, Walters Road, Swansea.

1889. Martin, The Hon. James, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Martindale, Warine Ben Hay, 82 New Bond Street, London, W.; and Overfield, Bickley, R.S.O., Kent.

1882. Masefield, Robert, 14 Markham Square, Chelsea, London, S.W.

1884. Massey, George, Post Office Chambers, Pitt Street, Sydney, New South Wales.

1890. Massey, Stephen, Messrs. B. and S. Massey, Openshaw, Manchester.

1867. Mather, William, M.P., Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China: (or care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.)

1891. Mathewson, Jeremiah Eugene, Tilghman's Sand-Blast Co., Bellefield Works, Bellefield Lane, Sheffield.

1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.

1886. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, Maxim Nordenfelt Guns and Ammunition Co., Victoria Mansions, 32 Victoria Street, Westminster, S.W.

1859. Maylor, William, Chesterleigh, Albemarle Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1891. McCredie, Arthur Latimer, 250 Pitt Street, Sydney, New South Wales. [*Ebony, Sydney.* 63.]

1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.; and The Cedars, Norwood Green, Southall.

1891. McFarlane, George, Bank of Scotland Buildings, 24 George Square, Glasgow. [*Asphodel, Glasgow.*]

1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C. [*Sahib, London.*]

1889. McIntyre, John Henry A., Lecturer on Mechanical Engineering, Allan Glen's School, Glasgow.

1881. McKay, John, 13 Grey Street, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 32 Wemyss Road, Blackheath, London, S.E.

1888. McLarty, Farquhar Matheson, Penang Foundry, Penang: (or care of William Bow, Thistle Engine Works, Paisley.)

1879. McLean, William Leckie Ewing, Renfrew Forge and Steel Co., Porterfield, Renfrew.

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Glasgow.*]

1891. Meade, Thomas de Courcy, Engineer, Hornsey District Board, 99 Southwood Lane, Highgate, London, N.

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1881. Meik, Charles Scott, care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.

1858. Meik, Thomas, 21 York Place, Edinburgh.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1891. Melville, William Charles, Superintendent Engineer, Liverpool Steam Tug Co., 44 Chapel Street, Liverpool.

1888. Melville, William Wilkie, 284 Ivydale Road, Nunhead, London, S.E.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Co., 50 Side, Newcastle-on-Tyne. [*William Menzies, Newcastle-on-Tyne. G.P.O.* 200. *Nor. Dis.* 1144.]

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]

1891. Metcalfe, Frederick Spencer, Pumping Station, Sewage Works, Burton-on-Trent.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 17 Victoria Street, Westminster, S.W.

1891. Middleton, Robert, Sheepscar Foundry, Leeds.

1891. Middleton, Robert Thomas, Superintendent of Bridge Works, Bombay Baroda and Central India Railway, Bombay, India.

1886. Midelton, Thomas, Aylesbury, Albemarle Street, North Kingston, Sydney, New South Wales.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1887. Miles, Frederick Blumenthal, Messrs. Bement Miles and Co., Callowhill and Twenty-first Streets, Philadelphia, United States.

1889. Miller, Adam, 205 Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1885. Miller, Harry William, care of Messrs. Chester and Gibb, Johannesburg, Transvaal, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, 7 Tower Buildings N., Water Street, Liverpool.

1885. Millis, Charles Thomas, Technical College, Finsbury, London, E.C.

1887. Milne, William, Locomotive Superintendent, Natal Government Railways, Durban, Natal.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., 17 Victoria Street, Westminster, S.W.; and The Manor House, Bexley, S.O., Kent.

1882. Molesworth, James Murray, Lee Cottage, Shawclough, near Rochdale: (or care of Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.)

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1885. Monk, Edwin, care of Josiah McGregor, Crown Buildings, 78 Queen Victoria Street, London, E.C.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S. O., Kent.

1876. Moore, Joseph, 1099 Adeline Street, Oakland, San Francisco, California; (or care of Ralph Moore, Government Inspector of Mines, 13 Clairmont Gardens, Glasgow.)

1880. Moreland, Richard, Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1889. Morgan, David John, Central Engineering Works, Cardiff.

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Morris, Charles, 5 Mangoe Lane, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1890. Morris, Francis Sanders, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1890. Morris, John Alfred (*Life Member*), Empire Works, 78 Great Bridgewater Street, Manchester.

1858. Mountain, Charles George, 7 Bothwell Street, Glasgow.

1886. Mountain, William Charles, Messrs. Ernest Scott and Co., Close Works, Newcastle-on-Tyne; and 9 St. George's Terrace, Jesmond, Newcastle-on-Tyne.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 37 Cross Street, Manchester. [1027.]

1876. Muirhead, Richard, Kentish Engineering Works, Maidstone.

1890. Müller, Henry Adolphus, Locomotive Superintendent, Municipal Railway, 3 North Road, Entally, Calcutta, India.

1890. Mumford, Charles Edward, St. Andrew's Works, Bury St. Edmunds.

1890. Munro, John, Merchant Venturers' Technical School, Unity Street, Bristol.

1890. Munro, Robert Douglas, Chief Engineer, Scottish Boiler Insurance and Engine Inspection Co., 13 Dundas Street, Glasgow.

1889. Münster, Bernard Adolph, care of Messrs. Jardine Matheson and Co., Yokohama, Japan.

1891. Murdoch, Robert Macmillan, Phœnix Metal Die and Engineering Co., 40 Princes Street, Stamford Street, Blackfriars, London, S.E.

1890. Murray, Alexander John, Chief Mechanical Engineer, Government Gun-Powder Factory, Kirkee, Bombay, India.

1890. Murray, Kenneth Sutherland, Brin's Oxygen Works, 69 Horseferry Road, Westminster, S.W.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1888. Myers, William Beswick (*Life Member*), 14 Victoria Street, Westminster, S.W.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1889. Nash, Thomas, Sheffield Testing Works, Blonk Street, Sheffield; and Guzerat House, Nether Edge, Sheffield.

1888. Nathan, Adolphus, Messrs. Marini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.

1891. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, 16 The Banks, High Street, Rochester.

1889. Needham, Joseph Edward, Patent Office, 25 Southampton Buildings, London, W.C.

1884. Nelson, John, 48 Bootham, York.

1887. Nelson, Sidney Herbert, Messrs. Samuel Worssam and Co., Oakley Works, King's Road, Chelsea, London, S.W.

1881. Nesfield, Arthur, Messrs. Simpson Mackirdy and Co., 29 South Castle Street, Liverpool.

1882. Nettlefold, Hugh, Screw Works, 16 Broad Street, Birmingham. [*Nettlefolds, Birmingham.*]

1890. Newton, Percy, Vassall Lodge, Addison Road, Kensington, London, W.

1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chili.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1891. Nicholson, Thomas, Crownpoint Boiler Works, St. Marnock Street, Crownpoint Road, Glasgow.

1877. Nicolson, Donald, 16 St. Helen's Place, London, E.C.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 43 York Street, Wynyard Square, Sydney, New South Wales.

1882. Nordenfelt, Thorsten, 9 Victoria Street, Westminster, S.W.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1883. North, Gamble, Pisagua, Chile: (or care of B. Depledge, Woolpack Buildings, 3 Gracechurch Street, London, E.C.)

1891. North, George, 90 Queen Street, London, E.C. [*Spero, London.*]

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; Woolpack Buildings, 3 Gracechurch Street, London, E.C.; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

1888. Norton, William Eardley, 8 Great George Street, Westminster, S.W.

1882. Nunneley, Thomas, 9 Beech Grove Terrace, Leeds.

1885. Oakes, Sir Reginald Louis, Bart., York Engineering Works, Leeman Road, York.

1887. O'Brien, Benjamin Thompson, 45 Fern Grove, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1890. Ockendon, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. O'Connor, Charles, 15 Wesley Street, Waterloo, near Liverpool.

1888. O'Donnell, John Patrick, 2 Great George Street, Westminster, S.W.; and Avondale, College Road, Bromley, Kent. [*ODonnell, London.*]

1887. O'Flyn, John Lucius, Messrs. L. and H. Guéret and Co., Exchange, Cardiff.

1889. Ogden, Fred, Patent Office, 25 Southampton Buildings, London, W.C.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C. [*Oaktree, London.*]

1882. Orange, James, Messrs. Danby Leigh and Orange, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield. [*Osborn, Sheffield.*]

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1859. Owen, Thomas, Midland Railway, Derby.

1868. Paget, Arthur, Loughborough. [*Paget Company, Loughborough.*]

1877. Panton, William Henry, Messrs. Dorman Long and Co., Middlesbrough.

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1872. Parker, Thomas, Locomotive Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1888. Parker, Thomas, Jun., Locomotive Department, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1891. Parker, Thomas, Chief Engineer, Electric Construction Corporation, Wolverhampton.

1879. Parker, William, 108 Fenchurch Street, London, E.C.; and Ash Dune, Catford Hill, London, S.E. [11053.]

1871. Parkes, Persehouse, Messrs. Persehouse Parkes and Co., 21 Drury Buildings, 21 Water Street, Liverpool. [*Fibrous, Liverpool.*]

1884. Parlane, William, Manager, Hong Kong Ice Company, Hong Kong, China.

1886. Parry, Alfred, Messrs. Parry and Co., Vulcan Iron Works, Calcutta, India: (or care of Messrs. J. D. Brown and Co., 5 and 7 Fenchurch Street London, E.C.)

1889. Parry, Evan Henry, Eagle Chambers, Adelaide Street, Swansea.

1878. Parsons, The Hon. Richard Clere, Oak Lea, Wimbledon Park, Surrey.

1886. Passmore, Frank Bailey, Mansion House Chambers, 11 Queen Victoria Street, London, E.C. [*Knarf, London.*]

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India : (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Paton, Robert J., Companhia McHardy, Campinas, São Paulo, Brazil.

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1891. Pattison, Joseph, 115 Bute Docks, Cardiff.

1891. Paul, Matthew, Jun., Messrs. Matthew Paul and Co., Levenford Works, Dumbarton.

1891. Paulson, Scott, Box 455, Johannesburg, Transvaal, South Africa : (or care of Dr. Paulson, Mountsorrel, near Loughborough.)

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, Messrs. Willans and Robinson, Ferry Works, Thames Ditton.

1890. Peacock, Francis, Locomotive Superintendent, Smyrna and Cassaba Railway, Smyrna, Asia Minor.

1890. Peacock, James Albert Wells, Assistant Locomotive Superintendent, Smyrna and Cassaba Railway, Smyrna, Asia Minor.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Pearce, George Cope, Ryefields, Ross.

1873. Pearce, Richard, Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1883. Peck, Walter, Gidlow Lodge, Wigan.

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.

1873. Penn, John, M.P., Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Healey Terrace, Fairfield, near Manchester.

1882. Perry, Alfred, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.

1890. Perry, Weston Alcock, Phosphor-Bronze Co., Birmingham; and Kenwood, St. Peter's Road, Birmingham.

1882. Petherick, Vernon, Messrs. Petherick and Co., Elevator and Hydraulic Engineers, Box 1046, General Post Office, Sydney, New South Wales.

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Henry Parnham, District Locomotive Superintendent, Eastern Bengal State Railway, Calcutta, India; and 71 Grosvenor Street, London, W.

1878. Phillips, John, 4 Corona Road, Burnt Ash Hill, Lee, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, Kimberley, South Africa; and care of H. Eckstein, Box 149, Johannesburg, Transvaal, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and Rochelle, Selhurst Road, South Norwood, London, S.E. [*Phicycle, London.*]

1890. Phillips, Walter, 108 Fenchurch Street, London, E.C.

1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore Works, Madras.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1888. Pilkington, Herbert, Midland Coal Coke and Iron Co., Apedale, near Newcastle, Staffordshire.

1883. Pillow, Edward, London and North Western Railway, Locomotive Department, Crewe.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France. [*Lethuillier Pinel, Rouen.*]

1882. Pirrie, John Sinclair, Austral Otis Elevator and Engineering Works, South Melbourne, Victoria: (or care of Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.)

1888. Pirrie, Norman, Messrs. Hunter Pirrie and Co., City Engineering Works, Wellington Street, N., Liverpool. [*Conical, Liverpool.*]

1888. Pirrie, William James, Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Jun., Linotype Co., 6 Serjeants' Inn, Fleet Street, London, E.C.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe (*Life Member*), Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John, Clydach Foundry, near Swansea.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1890. Poke, George Henry, Chief Engineer, Government Gun-Carriage Factory, Colaba, Bombay, India.

1886. Pollock, James, Fenchurch House, 5 and 7 Fenchurch Street, London, E.C. [*Specific, London.*]

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool. [*Pooley, Liverpool.*]

1890. Potter, William Henry, Parliament Chambers, Upper Parliament Street, Nottingham.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 117 Camberwell Grove, London, S.E.

1878. Powell, Henry Coke, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1890. Powell, James Richard, Pierhead Chambers, Cardiff.

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.

1891. Powles, Henry Handley Pridham, Faraday House, Charing Cross Road, London, W.C.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1890. Preece, William Henry, F.R.S., General Post Office, St. Martin's-le-Grand, London, E.C.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.

1856. Preston, Francis, Netherfield House, Kirkburton, near Huddersfield.

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 52 Queen Victoria Street, London, E.C. [*Indices, London.* 1533.]

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1890. Price, John, Inspecting Engineer, Workington.

1889. Price, John Bennett, Messrs. Charles Macintosh and Co., Cambridge Street, Manchester; and 13 Fishergate Hill, Preston.

1859. Price-Williams, Richard, 4 Victoria Mansions, 32 Victoria Street, Westminster, S.W. [*Spandrel, London.*]

1886. Price-Williams, Seymour William, 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W.

1874. Prosser, William Henry, Messrs. Harfield and Co., Blaydon-on-Tyne.

1885. Pudan, Oliver, Chief Engineer's Office, Cambria Iron Works, Johnstown, Pennsylvania, U.S.: (or 15 Princes Street, Yeovil.)

1890. Pugh, Charles Henry, Whitworth Works, Rea Street South, Birmingham.

1887. Pullen, William Wade Fitzherbert, 25 Clare Street, Riverside, Cardiff.

1884. Puplett, Samuel, Albany Buildings, 47 Victoria Street, Westminster, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1887. Pyne, Thomas Salter, care of H.H. the Ameer of Afghanistan, Cabul; care of Messrs. Walsh Lovett and Co., 10 Ludgate Hill, Birmingham.

1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield. [*Radford, Sheffield.*]

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]

1885. Rainforth, William, Jun., Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness; and Reform Chambers, 105 Pall Mall, London, S.W.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich. [*Waterside, Ipswich.*]

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, 9 Victoria Street, Westminster, S.W. [*Ransomes, Westminster.*]

1888. Rapley, Frederick Harvey, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1889. Ratcliffe, James Thomas, Fabric von Izr. K. Poznanski, Lodz, Russian Poland.

1883. Rathbone, Edgar Philip, Standard Bank Buildings, and P. O. Box 963, Johannesburg, Transvaal, South Africa. [*Viking, Johannesburg.*]

1867. Ratliffe, George, 7A Laurence Pountney Hill, London, E.C.

1862. Ravenhill, John R., Delaford, Iver, near Uxbridge.

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham. [*Metro, Birmingham.*]

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Co., West Docks, South Shields.

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 64 Mark Lane, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1891. Reed, Thomas Alfred, 2 Bute Crescent, Cardiff.

1884. Rees, William Thomas, Mining Engineer, Gadlys Cottage, Aberdare.

1890. Reeves, Frank, Assistant Engineer, Ferro Carril de Buenos Aires al Pacifico, 228 Calle Piedad, Buenos Aires, Argentine Republic.

1891. Reid, Hugh (*Life Member*), Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1889. Rendell, Alan Wood, Locomotive Superintendent, East Indian Railway, Jumalpore, Bengal, India: (or Ravenswood, Byculla Park, Enfield.)

1890. Rendell, Samuel, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and 306 Fairfield Road, Fairfield, near Manchester.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, 2 Eccleston Square, London, S.W.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1883. Reunert, Theodore, Box 209, Kimberley, South Africa; Box 92, Johannesburg, Transvaal, South Africa: (or care of Messrs. Findlay Durham and Brodie, 43–46 Threadneedle Street, London, E.C.)

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Wardha Coal State Railway, Warora, Central Provinces, India; care of Messrs. Grindlay Groom and Co., Bombay, India.

1890. Rice, Thomas Sydney, Messrs. Harvey Graham and Co., 10 Bush Lane, Cannon Street, London, E.C.

1866. Richards, Edward Windsor, Low Moor Iron Works, near Bradford.

1882. Richards, George, Suffolk House, Laurence Pountney Hill, London, E.C.

1884. Richards, Lewis, West Cumberland Iron and Steel Works, Workington; and Derwent View, Workington.

1863. Richardson, The Hon. Edward, C.M.G., Wellington, New Zealand.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1891. Richardson, John Scott, Arequipa, Peru: (or care of Joseph Richardson, 4 Blackhall Road, Oxford.

1887. Richardson, Thomas, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1884. Riches, Charles Hurry, Assistant Locomotive Superintendent, Taff Vale Railway, Cardiff.

1890. Riches, Glenford Mitchell, Fish Dock, Grimsby.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1889. Richmond, Joseph, New Sun Iron Works, Burdett Road, Bow, London, E.; and 30 Kirby Street, Hatton Garden, London, E.C.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Swalwell Steel Works, Newcastle-on-Tyne.

1887. Rickie, John, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1884. Ripper, William, Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1889. Riva, Enrico, Locomotive and Carriage Superintendent, Rete Adriatica, Ferrovie Meridionale, Florence, Italy.

1879. Rixom, Alfred John, 1 Gordon Villas, Park Road, Loughborough.

1891. Roberts, Hugh Jorwerth, Messrs. Burn and Co., Howrah Iron Works, Howrah, Calcutta, India: (or care of Messrs. John D. Brown and Co., 5 and 7 Fenchurch Street, London, E.C.)

1887. Roberts, Thomas, Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, Argentine Great Western Railway, Mendoza, Argentine Republic.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Herbert J. Stockton, 16 Philpot Lane, London, E.C.)

1883. Robins, Edward, 22 Conduit Street, London, W.

1890. Robinson, Frederick Arthur, Messrs. F. A. Robinson and Co., 69 Cornhill, London, E.C.

1874. Robinson, Henry, Professor of Surveying and Civil Engineering, King's College, Strand, London, W.C.; and 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and Westwood Hall, Leek, near Stoke-upon-Trent.

1886. Robinson, John, Barry Dock and Railways, Barry, near Cardiff.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow.

1891. Robinson, John George, Locomotive and Carriage Engineer, Waterford and Limerick Railway, Limerick.

1890. Robinson, Sydney Jessop, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1891. Roche, Francis James, Shanghai Water Works, Shanghai, China.

1890. Rochford, John, Commissioners of Irish Lights, Westmoreland Street, Dublin.

1888. Rock, John William, Exchange Corner, Pitt Street, Sydney, New South Wales: (or care of E. G. Rock, The Red House, Ingatestone.)

1879. Rodger, William, care of Messrs. C. H. B. Forbes and Co., 3 Elphinstone Circle, Bombay: (or care of Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.)

1884. Rodrigues, José Maria de Chermont, Rua de S. Pedro 54 sobrado, Rio de Janeiro, Brazil.

1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.

1885. Rogers, Henry John, Watford Iron Works, Watford. [*Engineer, Watford.*]

1887. Rogers, Horace Wyon, 43 Upper Thames Street, London, E.C.

1889. Rosenthal, James Hermann, Babcock and Wilcox Boiler Co., 114 Newgate Street, London, E.C.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1856. Rouse, Frederick, Locomotive Department, Great Northern Railway, Peterborough.

1878. Routh, William Pole, Sutton Court, Sutton, Surrey.

1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.

1891. Rowland, Bartholomew Richmond, Messrs. Luke and Spencer, Ardwick, Manchester.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, General Manager, Bute Shipbuilding Engineering and Dry Dock Co., Bute Dry Dock, Roath Basin, Cardiff. [*Caisson, Cardiff.*]

1877. Rutter, Edward, Hotham House, Heron Court, Richmond, Surrey.

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1883. Ryder, George, Turner Bridge Iron Works, Tong, near Bolton. [*Ryder, Machinist, Tong, Bolton.* 33A.]

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1883. Sadoine, Baron Eugène, 13 Place de Bronckart, Liége, Belgium.

1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 9 Park Crescent, Portland Place, London, W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and 23 St Ermin's Mansions, Westminster, S.W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1890. Sandberg, Christer Peter, 19 Great George Street, Westminster, S.W.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.

1871. Sanders, Richard David, Hartfield House, Eastbourne.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1891. Sands, Harold, 3 Harcourt Buildings, Inner Temple, London, E.C.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]

1891. Savill, Arthur Slater, Exhaust Steam Injector Company, 4 St. Ann's Square, Manchester.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.*]; and North Court, Hassocks, R.S.O., Sussex.

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1890. Schofield, George Andrew, Chief Assistant Locomotive and Carriage Superintendent, Chilian State Railways, Casilla No. 193, Santiago, Chili.

1886. Scholes, William Henry, 1255 n/n Rivadavia, Buenos Aires, Argentine Republic: (or care of George Scholes, 79 Mark Lane, London, E.C.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W.

1880. Schram, Richard, 17A Great George Street, Westminster, S.W. [*Schram, London.*]

1890. Schroller, William, 16 Baldry Gardens, Streatham Common, London, S.W.

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Lyncot, Romford.

1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India: 20 Loanhead Terrace, Aberdeen: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1891. Scott, Arthur Forbes, 69 Swan Arcade, Bradford.

1882. Scott, Charles Herbert, Messrs. Summers and Scott, High Orchard Iron Works, Gloucester.

1890. Scott, Frederick McClure, 89 Victoria Street, Liverpool.

1891. Scott, F. Walter, Messrs. George Scott and Son, 44 and 46 Christian Street, London, E. [*Thirty-four, London.* 4390.]

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1881. Scott, George Innes, Three Indian King's Court, Quayside, Newcastle-on-Tyne.

1891. Scott, Henry John, 18 Castellain Road, Maida Hill, London, W.

1877. Scott, Irving M., Union Iron Works, San Francisco, California.

1881. Scott, James, General Manager, President Land and Exploration Co., Pretoria, Transvaal, South Africa: (or Douglasfield, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1885. Scott, Robert, 50 Cornwall Road, Westbourne Park, London, W.

1891. Scott, Robert Julian, School of Engineering, Canterbury College, Christchurch, New Zealand.

1861. Scott, Walter Henry, Locomotive Superintendent, Ferro Carril del Norte, San Eugenio, Uruguay: (or care of H. Eaton, 75 Tulse Hill, London, S.W.)

1884. Scott-Moncrieff, William Dundas, 86 Newman Street, Oxford Street, London, W.

1868. Scriven, Charles, Whinfield Mount, Chapel Allerton, Leeds. [*Scriven, Leeds.*]

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1864. Seddon, John, 98 Wallgate, Wigan.

1886. Seddon, Robert Barlow, Manager, Wigan Wagon Works, Wigan.

1891. Selby, Millin, 14 Rue de la Gare, Lille, France.

1882. Selfe, Norman, 279 George Street, Sydney, New South Wales.

1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1888. Sellers, George, Holly Cottage, Wakefield.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1891. Selliet, Alphonse Louis, 74 St. James Street, Sanfernando, Trinidad.

1889. Selman, David Codrington, Professor of Mathematics, University College, Bristol.

1881. Sennett, Richard, Messrs. Maudslay Sons and Field, Lambeth, London, S.E.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah, Bengal; 7 Hastings Street, Calcutta; and 57 Upper Berkeley Street, London, W.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1890. Shardlow, Ambrose, Ealing Works, Washford Road, Attercliffe, Sheffield.

1891. Sharp, Henry, 23 College Hill, London, E.C.; and Loseley Hurst, Bournemouth.

1875. Sharp, Thomas Budworth, Consulting Engineer, Muntz Metal Works, Birmingham; and County Chambers A, Martineau Street, Birmingham. [*Budworth, Birmingham.*]

1882. Sharrock, Samuel Lord, New South Wales Club, Sydney, New South Wales.

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Messrs. W. Shaw Kirtley and Co., Wellington Cast Steel Foundry, Middlesbrough.

1890. Sheldon, Harry Cecil, Messrs. W. P. Thompson and Boult, 63 Long Row, Nottingham.

1856. Shelley, Charles Percy Bysshe, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W.

1891. Shenton, James, Messrs. Tinker Shenton and Co., Hyde Boiler Works, Hyde, near Manchester.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1875. Sheppard, Herbert Gurney, Chief Engineer, Assioot-Girgeh Railway, Assioot, Upper Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1888. Shin, Tsuneta, Director, Ishikawajima Shipbuilding and Engineering Co., Tokyo, Japan.

1889. Shone, Isaac, Great George Street Chambers, Westminster, S.W.

1890. Shoosmith, Harry, Messrs. G. Kynoch and Co., Lion Works, Witton, Birmingham.

1890. Shore, Alfred Thomas, Government Inspector of Steam Boilers, Custom House, Bombay, India.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1891. Siemens, Alexander (*Life Member*), 12 Queen Anne's Gate, Westminster, S.W.

1888. Siemens, Frederick, 10 Queen Anne's Gate, Westminster, S.W.

1888. Siemens, Dr. Werner, Messrs. Siemens and Halske, 94 Markgrafen Strasse, Berlin.

1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1885. Simpson, James Thomas, Executive Engineer, Public Works Department, Shwebo, Upper Burmah.

1882. Simpson, John Harwood, Manchester Ship Canal, 65 King Street, Manchester.

1889. Sinclair, Nisbet, Messrs. Robert Napier and Sons, Lancefield House, Glasgow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

1891. Sinclair, Russell, 81 Pitt Street, Sydney, New South Wales.

1881. Sisson, William, Quay Street Iron Works, Gloucester. [*Sisson, Gloucester.*]

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 25 Royal York Crescent, Clifton, Bristol.

1885. Slight, William Hooper, care of B. Powell, Soerabaya, Java: (or Woodborough Vicarage, Nottingham.)

1891. Sloan, Robert Alexander, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1886. Small, James Milu, Messrs. Urquhart and Co., 11 Victoria Street, Westminster, S.W.

1889. Smelt, John Dann, Argentine Great Western Railway, 4 Finsbury Circus, London, E.C.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, North Shields.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1891. Smith, John Reney, 16 Seaton Buildings, 17 Water Street, Liverpool.

1890. Smith, John Windle, Messrs. Marshall Sons and Co., and Messrs. Walsh Lovett and Co., 308 Calle Peru, Buenos Aires, Argentine Republic: (or care of Edward Smith, The "Lock," Gainsborough.)

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness; and Rhine Hill, Stratford-on-Avon.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 18 Abingdon Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, 24 Brazennose Street, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 124 Hagley Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1890. Smith, Thomas Ridsdill, Earle's Shipbuilding and Engineering Works, Hull.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1890. Smith, William, London and Manchester Plate Glass Co., Sutton, St. Helen's, Lancashire.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, F.R.S., Ennerdale Hall, Frizington, near Carnforth.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W. [*Sopwith, London.* 3175.]

1887. Sorabji, Shapurji, Bombay Foundry and Engine Works, Khetwady, Bombay: (or care of Messrs. S. and E. Ransome and Co., 10 Essex Street, Strand, London, W.C.)

1884. Soulsby, James Charlton, 17 Mount Stuart Square, Cardiff.

1889. Souter-Robertson, David, Assistant Superintendent, Government Canal Foundry and Workshops, Roorkee, North Western Provinces, India.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1877. Soyres, Francis Johnstone de, 4 Arlington Villas, Clifton, near Bristol.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, 77 Cannon Street, London, E.C.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Globe Tube Works, Wednesbury [*Tubes, Wednesbury.*]; and 3 Queen Street Place, Cannon Street, London, E.C. [*Tubes, London.*]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Ardwick, Manchester; and The Meadows, Alderley Edge, near Manchester.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1891. Spencer, William, Messrs. James Spencer and Co., Chamber Iron Works, Hollinwood, near Manchester.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India; and Bron-y-garth, Portmadoc, R.S.O., Carnarvonshire.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W.

1888. Stanley, Harry Frank, Messrs. Pontifex and Wood, Farringdon Works, Shoe Lane, London, E.C.; and 84 Finsbury Park Road, London, N.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.

1884. Stanton, Frederic Barry, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W. [*Precursor, London.*]

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]

1888. Stephenson-Peach, William John, Askew Hill, Repton, Burton-on-Trent.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1891. Stevens, James, 9 and 11 Fenchurch Avenue, London, E.C.

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.
1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.
1887. Stewart, Andrew, 41 Oswald Street, Glasgow.
1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]
1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]
1888. Stiff, William Charles, Credenda Seamless Steel-Tube Works, Ledsam Street, Birmingham.
1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.
1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1888. Stirling, Robert, Locomotive Department, North Eastern Railway, Gateshead.
1875. Stoker, Frederick William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent.
1877. Stokes, Alfred Allen, Elmcote, Godalming.
1887. Stone, Frank Holmes, P.O. Box, Kingston, Jamaica.
1877. Stothert, George Kelson, Steam Ship Works, Bristol.
1888. Strachan, James, Stenton, near Prestonkirk.
1888. Straker, Sidney, Messrs. Ewen and Straker, 37 Walbrook, London, E.C.; and 240 Stanstead Road, Forest Hill, London, S.E.
1891. Stringer, William, 20 Mount Street, Manchester.
1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil: (or 1 Albion Street, Hyde Park, London, W.)
1873. Strype, William George, 115 Grafton Street, Dublin. [*Strype, Dublin.*]
1878. Stuart, Professor James, M.P., 24 Grosvenor Road, London, S.W.
1889. Stuart-Hartland, Dare Arthur, Messrs. John Fowler and Co., 31 Dalhousie Square South, Calcutta, India.
1882. Sturgeon, John, Shrublands, Hoole Road, Chester.
1890. Stutzer, Waldemar, Koltchugin Brass and Copper Mill Co., Alexandrov Station, Jaroslav Railroad, Russia.
1882. Sugden, Thomas, Babcock and Wilcox Co., 114 Newgate Street, London, E.C.
1890. Sulzer, Jacob, Messrs. Sulzer Brothers, Winterthur, Switzerland.
1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, 36 Bedford Street, Strand, London, W.C.; and Sunnyside Cottage, Thames Ditton, Surrey.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1887. Suverkrop, John Peter, Chief Engineer, East Tennessee Land Co., Harriman, Tennessee, United States: (or 1 Kew Gardens Road, Kew, Surrey.)

1882. Swaine, John, Messrs. Wright Butler and Co., Panteg Steel Works, near Newport, Monmouthshire.

1884. Swan, Joseph Wilson, 57 Holborn Viaduct, London, E.C.; and Lauriston, Bromley, Kent.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne; and 117 Park Road, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, Clent House, Stourbridge.

1890. Swinerd, Edward, Superintendent, Locomotive Carriage and Wagon Departments, Mogyana Railway, Campinas, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, Laurence Pountney Hill, London, E.C.)

1890. Swinnerton, Robert Allen William, Executive Engineer, Public Works Department, Ellichpore, Berar, India.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and The Corner House, Shortlands, S.O., Kent.

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe; and 4 Wellington Villas, Wellington Square, Crewe.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1876. Taunton, Richard Hobbs, 10 Coleshill Street, Birmingham.

1882. Tayler, Alexander James Wallis, 77 Victoria Road, Kilburn, London, N.W.

1874. Taylor, Arthur, Manager, Lahat Tin Mines, Perak, viâ Penang; and 6 Queen Street Place, Upper Thames Street, London, E.C.: (or 21 Victoria Road, Kensington, London, W.)

1887. Taylor, James, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, 26 Rue de Caumartin, Paris; and 21 Victoria Road, Kensington, London, W.

1882. Taylor, Robert Henry, 55 Kent House Road, Sydenham, London, S.E.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, Stafford House, Hednesford, near Stafford.

1891. Tetlow, Ernest, Messrs. Tetlow Brothers, Bottoms Iron Works, Hollinwood, near Manchester.

1877. Thom, William, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1889. Thomas, James Donnithorne, 25A Old Broad Street, London, E.C. [*Kooringa, London.*]

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1888. Thomas, Philip Alexander, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Argument, London.*]

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1891. Thompson, James, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1875. Thompson, John, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1880. Thompson, Thomas William, Eastham Ferry Pier, near Birkenhead.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1889. Thomson, Robert McNidar, Kobe Engine Works, Kobe, Japan.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1888. Thornton, Robert Samuel, West's Patent Press Co., Etawah, North Western Provinces, India.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Engineer, New South Wales Government Railways, Eveleigh Workshops, Sydney, New South Wales: (or care of Joseph Meilbek, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.)

1884. Thwaites, Arthur Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford. [*Thwaites, Bradford.* 325.]

1887. Thwaites, Edward Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford.

1891. Tilley, Albert, Astilleros del Nervion, Bilbao, Spain.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium. [*Société Meuse, Liége.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 38 Croom's Hill, Greenwich, London, S.E.

1890. Titley, Arthur, Gravelly Hill, Birmingham.

1888. Todd, Robert Ernest, Mechanical Engineer, Tucuman, Estacion Provincia, Argentine Republic: (or care of William H. Todd, County Buildings, Land of Green Ginger, Hull.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1857. Tomlinson, Joseph, 64 Priory Road, West Hampstead, London, N.W.

1888. Topple, Charles James, Machinery Department, Royal Arsenal, Woolwich.

1883. Tower, Beauchamp, 5 Queen Anne's Gate, Westminster, S.W.

1889. Towler, Alfred, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1886. Towne, Henry Robinson, Yale and Towne Manufacturing Co., Stamford, Connecticut, United States.

1890. Trail, John, Swansea Dry Docks and Engineering Co., Swansea.

1888. Travis, Henry, Machinery Department, Royal Arsenal, Woolwich.

1889. Tremerry, William Penrose, 73 Via Milano, Genoa, Italy.

1883. Trentham, William Henry, 2 Hervey Road, Shooter's Hill Road, London, S.E.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1886. Trew, James Bradford, High Street, Watford, Herts.

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1885. Trueman, Thomas Brynalyn, Ferro Carril Buenos Aires al Pacifico, Junin, Argentine Republic: (or care of Thomas R. Trueman, 3 The Barons, Twickenham.)

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Bishopbriggs, Glasgow.

1885. Turnbull, John, Jun., 255 Bath Street, Glasgow. [*Turbine, Glasgow.*]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1886. Turner, George Reynolds, Vulcan Iron Works, Langley Mill, near Nottingham; and 81 Highgate Road, London, N.W.

1887. Turner, Joshua Alfred Alexander, Superintendent and Chief Engineer, Government Steam Flour Mills, Poona, India.

1882. Turner, Thomas, New British Iron Works, Corngreaves, near Birmingham.

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1891. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W. [*Tweddell, Westminster, London.*]; and Meopham Court, near Gravesend.

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 2 Newgate Street, London, E.C.

1889. Tyrrell, Joseph John, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1878. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Tamboff Government, Russia.

1880. Valon, William Andrew McIntosh, 140 and 141 Temple Chambers, Temple Avenue, London, E.C.; and Ramsgate. [*Valon, Ramsgate.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Vaunting, Manchester.* 5106.]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]

1889. Vesian, John Stuart Ellis de, 5 Crown Court, Cheapside, London, E.C. [*Biceps, London.*]

1891. Vicars, John, Messrs. T. and T. Vicars, Furnace Foundry, Earlestown, Newton-le-Willows, Lancashire.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1888. Voysey, Henry Wesley, 1 Fordwych Road, Brondesbury, London, N.W.

1883. Waddell, James, 9 Ashton Terrace, Dowanhill, Glasgow.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, The Hon. Nowrosjee Nesserwanjee, C.I.E., Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Tardeo, Bombay.*]

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1875. Wailes, John William, Calderbank Steel and Coal Co., Calderbank, near Airdrie; and Monkland House, near Airdrie.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1888. Waister, William Henry, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1890. Walkeden, George Henry, Temperance Life Buildings, Swanston Street, Melbourne, Victoria.

1891. Walker, Arthur Tannett, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds. [*Tannett Walker, Leeds.*]

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1890. Walker, Henry, 37 Heaton Grove, Newcastle-on-Tyne.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 3 Alexandra Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Matthew, 16 London Street, Fenchurch Street, London, E.C.

1886. Walker, Robert John, 33 Liversidge Road, Birkenhead.

1884. Walker, Sydney Ferris, Cardiff Electrical Works, Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Hunter's Forge, New Bridge Street, Newcastle-on-Tyne. [*Dynamo, Newcastle-on-Tyne.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E. [*Bromo, London.*]

1890. Walker, William George, University College, Bristol.

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1881. Walkinshaw, Frank, Hartley Grange, Winchfield.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1891. Walmsley, John, Queen's Mills, Huddersfield.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 49 New Road, Grays, S.O., Essex; and 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, 24 Church Lane, Smethwick, near Birmingham.

1876. Ward, William Meese, Newton Villa, Claremont Road, Handsworth, R.O., near Birmingham.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, R.O., near Birmingham. [*Bolts, Birmingham.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.

1885. Warren, Henry John, Jun., Don Pedro Mining Co., Morro de St. Anna, Marianna, Brazil : (or Lynton Villa, Camborne.)

1885. Warren, William, care of Messrs. Jardine Matheson and Co., Hong Kong, China : 199 Winchester House, London, E.C. : (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.) [*Wakeful, London ; or Hong Kong.*]

1882. Warsop, Henry, Clarendon Hotel, Nottingham.

1889. Warsop, Thomas, Coniston Copper Mines, Coniston, S.O., Lancashire.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1891. Waterous, Julius E., Waterous Engine Works Co., Brantford, Ontario, Canada.

1881. Watkins, Alfred, 2 Westcombe Park Road, Blackheath, London, S.E.

1862. Watkins, Richard, 71 Blenheim Crescent, London, W.

1890. Watkinson, William Henry, Central Higher Board School, Orchard Lane, Sheffield.

1890. Watson, George Coghlan, Manganese Bronze and Brass Co., St. George's Wharf, Deptford, London, S.E.; and 1 Farquharson Road, Croydon.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Glasgow.

1891. Watt, Charles, Melbourne Cable Tramway, 418 Little Collins Street, Melbourne, Victoria.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1884. Webb, Richard George, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India: (or care of Francis Webb, 31 Southampton Buildings, Chancery Lane, London, E.C.).

1890. Webster, John James, 39 Victoria Street, Westminster, S.W.

1887. Webster, William, care of Messrs. J. M. Lyon and Co., Engineers, Singapore.

1883. Weck, Friedrich, Cambridge Buildings, John Bright Street, Birmingham.

1891. Weightman, Walter James, care of Messrs. King King and Co., Bombay, India.

1888. Wellman, Samuel T., Wellman Iron and Steel Works, Thurlow, Pennsylvania, United States.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokyo, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 14 Castle Street, Liverpool. [*Referee, Liverpool.*]

1891. West, Leonard, Ravenhead Plate Glass Works, St. Helen's, Lancashire.

1874. West, Nicholas James, 36 Upper Park Road, Hampstead, London, N.W.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Dunlaces, London.* 3199.]

1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Bangkok, Siam: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1891. Westgarth, Tom, Messrs. Westgarth English and Co., Middlesbrough. [*Westgarth, Middlesbrough.* 5041.]

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York: P.O. Box 230, Ridgewood, New Jersey, United States.

1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1888. Weyman, James Edwardes, Messrs. Weyman and Johnson, Church Acre Iron Works, Guildford.

1884. Whieldon, John Henry, 94 Victoria Street, Westminster, S.W.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, Messrs. Sundheim and Doetsch, Huelva, Spain.

1874. White, Henry Watkins, 23 Leadenhall Street, London, E.C.; and 122 Lavender Hill, London, S.W.

1888. White, William Henry, C.B., F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

1885. Whitehead, James George, Mechanical Engineer, Hacienda San Nicolas, Puerto de Supe, Peru.

1890. Whitehouse, Edwin Edward Joseph, Monkbridge Iron Works, Leeds.

1876. Whiteley, William, St. Kilda, Bickerton Road, Birkdale, Southport.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds. [*Torpedo, Leeds.*]

1891. Whittaker, John, Messrs. William Whittaker and Sons, Sun Iron Works, Oldham.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1888. Whittle, John, Union Railway Wagon Works, Chorley.

1878. Whytehead, Hugh Edward, North Staffordshire Tramways, Stoke-on-Trent.

1878. Wicks, Henry, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of John Spencer, 125 West Regent Street, Glasgow.)

1863. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1891. Widdowson, John Henry, Britannia Works, Ordsal Lane, Salford, Manchester.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1889. Wigham, John Richardson, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1881. Wigzell, Eustace Ernest, Billiter House, Billiter Street, London, E.C. [*Wigzell, London.* 1844.]

1890. Wild, John, Falcon Iron Works, Oldham. [*Falcon, Oldham.*]

1882. Wilder, John, Yield Hall Foundry, Reading.

1886. Wildridge, John, Consulting Engineer and Marine Superintendent, Eastern and Australian Steamship Co., 34 Leadenhall Street, London, E.C.; and care of Messrs. Gibbs Bright and Co., Pitt Street, Sydney, New South Wales.

1890. Wildy, William Lawrence, 9 Castlegate, Grantham.

1888. Willans, Peter William, Messrs. Willans and Robinson, Ferry Works, Thames Ditton, Surrey. [*Willans, Thamesditton.*]

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1883. Williams, Edward Leader, Engineer, Manchester Ship Canal Co., 41 Spring Gardens, Manchester. [*Leader, Manchester.* 688.]

1884. Williams, John Begby, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1885. Williams, Nicholas Thomas, New Morgan Gold Mining Co., Dolgelly.

1847. Williams, Richard, Brunswick House, Wednesbury.

1890. Williams, Thomas David, Egremont, Battle Road, Ore, near Hastings.

1881. Williams, William Freke Maxwell, 29 Great St. Helen's, London, E.C. [*Wabash, London.*]

1873. Williams, William Lawrence, 16 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1889. Williams, William Walton, Jun., Las Trojes, Maravatio, Michoacan, Mexico.

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington.

1870. Willman, Charles, 26 Albert Road, Middlesbrough.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1872. Wilson, Alfred, The Firs, Norton, near Stourbridge.

1867. Wilson, Henry, 23 Pollard Street, South Shields.

1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt; Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, 24 Lincoln's Inn Fields, London, W.C. [*Palacol, London.*]

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1890. Wilson, Joseph William, Jun., Vice-Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1880. Wilson, Robert, 10 St. Bride Street, London, E.C.; and 7 St. Andrew's Place, Regent's Park, London, N.W.

1883. Wilson, Robert, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.

1890. Wilson, Robert James, Locomotive Works, Ferro Carril Central Norte, Cordoba, Argentine Republic.

1891. Wilson, Thomas, Morro Foundry, Iquique, Chile.

1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)

1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1891. Wimshurst, James Edgar, Messrs. William Esplen, Son, and Swainston, Billiter Buildings, 22 Billiter Street, London, E.C.

1890. Winder, Charles Aston, Messrs. Winder Brothers, Royds Works, Attercliffe, Sheffield.

1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.

1890. Wingfield, Digby Charles, Messrs. Thomas Piggott and Co., Spring Hill, Birmingham.

1887. Winmill, George, Locomotive and Carriage Superintendent, Oudh and Rohilkund Railway, Lucknow, India: (or Hare Street, Romford.)

1872. Winstanley, Robert, Mining Engineer, 28 Deansgate, Manchester.

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 2766.]

1871. Withy, Edward, Cleveland House, Remuera, Auckland, New Zealand.

1884. Withy, Henry, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]

1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Richard, 17 Dudley Street, Moss Side, Manchester.

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Amoy, China: (or 17 Dudley Street, Moss Side, Manchester.)

1888. Wolff, Gustav William, Messrs. Harland and Wolff, Belfast.

1881. Wood, Edward Malcolm, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W.

1887. Wood, Henry, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1885. Wood, Robert Henry, 15 Bainbrigge Road, Headingley, Leeds.

1884. Wood, Sidney Prescott, Semaphore Iron Works, Newport, Melbourne, Victoria: (or care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.)

1890. Wood, Thomas Royle, Assistant Locomotive Superintendent, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1890. Wood, William, 4 Wolfington Road, West Norwood, London, S.E.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1888. Woodford, Ethelbert George, Broad Street Avenue, London, E.C.

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1874. Worsdell, Thomas William, Stonycroft, Arnside, near Carnforth.

1884. Worssam, Charles Smith, 35 Queen Victoria Street, London, E.C.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)

1888. Worthington, Edgar, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and 243 Upper Brook Street, Manchester.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and Mill Bank, Vicarage Lane, Bowdon, R.O., near Altrincham.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester. [*Wrens, Manchester.*]

1881. Wrench, John Mervyn, District Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and Arundel House, Lower Road, Richmond, Surrey.

1860. Wright, Joseph, 16 Great George Street, Westminster, S.W.; and Lawnswood, Alexandra Road, Upper Norwood, London, S.E.

1878. Wright, William Barton, Rosslyn, Cleveland Road, Ealing, London, W.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1891. Wroe, Joseph, 6 Richmond Grove East, Manchester.

1891. Wylde, Thomas, P.O. Box 455, Johannesburg, Transvaal, South Africa.

1886. Wylie, James, 79 Sycamore Road, Handsworth, R.O., Birmingham.

1865. Wylie, Andrew, 1 Leicester Street, Southport.

1883. Wynne-Edwards, Thomas Alured, Agricultural Engineering Works, Denbigh. [*Foundry, Denbigh.*]

1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.

1889. Yarrow, Alfred Fernandez, Isle of Dogs, Poplar, London, E.

1878. Yates, Henry, Brantford, Ontario, Canada.

1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)

1881. Yates, Louis Edmund Hasselts, District Locomotive Superintendent, Eastern Bengal State Railway, Sealdah, Calcutta: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. York, Francis Colin, Locomotive Superintendent, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of Messrs. Samuel York Sons and Co., Snow Hill, Wolverhampton.)

1889. Young, David, 11 and 12 Southampton Buildings, London, W.C.

1879. Young, George Scholey, Engineer, Thames Iron Works, Orchard Yard, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Engine and Iron Works, Fence Houses.

1879. Young, James, Salroyd, 21 Cambalt Road, Putney, London, S.W.

1887. Young, William Andrew, Messrs. Lobnitz and Co., Renfrew, near Paisley. [*Lobnitz, Renfrew.* 57, *Paisley.*]

1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Zimmer, George Friedrich, care of J. Harrison Carter, 82 Mark Lane, London, E.C.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Cross George Street, Sheffield.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland; and The Glen, Newry, Ireland.

1889. Barr, John, Glenfield Engineering Works, East Shaw Street, Kilmarnock.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1890. Birch, John Grant, 10 and 11 Queen Street Place, London, E.C.

1888. Brown, Harold, 2 Bond Court, Walbrook, London, E.C.

1890. Burt, John Mowlem, Messrs. John Mowlem and Co., 19 Grosvenor Road, Pimlico, London, S.W.

1891. Carter, Frederick Heathcote, 9 Oxford Street, Manchester. [*Girder, Manchester.*]

1889. Castle, Frederick George, The People's Palace Technical Schools, Mile End Road, London, E.

1889. Chamberlain, John George, Messrs. Joseph Wright and Co., Neptune Forge, Tipton.

1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1887. Chubb, Edward George, Ironbridge Gas Works, Ironbridge, R.S.O., Shropshire.

1890. Chubb, Richard, Messrs. Gillison and Chadwick, 10 Tower Buildings, Liverpool.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]

1891. Cornett, James Porteus, Ford Paper Works, near Sunderland. [*Ford, Hylton. Nor. Dis.* 135.]

1890. Day, Arthur Godfrey, Municipal Technical School, Birmingham.

1883. Fairholme, Capt. Charles, R.N., Heberlein Self-acting Railway Brake Co., 18 St. Dunstan's Hill, London, E.C.

1891. Foster, George, Hecla Foundry Steel Works, Sheffield; and 40 Dixon Street, Rotherham.

1889. Goiby, Frederick William, 36 Chancery Lane, London, W.C.

1889. Götz, Carl Johann Wilhelm, Messrs. John M. Sumner and Co., 2 Brazennose Street, Manchester.

1889. Gregory, George Francis, Boarzell, Hawkhurst.

1887. Hind, Enoch, Edgar Rise, Nottingham.

1891. Jackman, Joseph, Persberg Steel Works, Sheffield.

1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]

1882. Jackson, William, Kingston Cotton Mill, Hull. [*Cotton, Hull.*]

1891. Jennings, George Henry, Stangate, Lambeth, London, S.E. [*Jennings, London.* 4680.]

1890. Jennings, Sidney, Stangate, Lambeth, London, S.E. [*Jennings, London.* 4680.]

1884. Livesey, Sir Joseph Montague, Bart., Stourton Hall, Horncastle.

1865. Longsdon, Alfred, 9 New Broad Street, London, E.C.

1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.* 131.]

1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]

1890. McGillivray, William, Messrs. Austin McGillivray and Co., Falcon Works, Sheffield. [*Austin, Sheffield.*]

1889. McKinnel, William, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1891. McMeekin, Adam, Cogry Flax Spinning Mills, Doagh R.S.O., Co. Antrim, Ireland.

1890. Meggitt, Samuel Newton, Messrs. Ibbotson Brothers and Co., Globe Steel Works, Sheffield.

1889. Miles, William Henry, Town Engineer, Sanitary Board, Johannesburg, Transvaal, South Africa.

1891. Monie, Hugh, Jun., Textile Section, Victoria Jubilee Technical Institute, Byculla, Bombay, India: (or care of Hugh Monie, Springfield, Belfast.)

1889. Nasmith, Joseph, 4 Arcade Chambers, St. Mary's Gate, Manchester.

1887. Neville, Edward Hermann, Messrs. Julius G. Neville and Co., Oriel Chambers, Liverpool. [*Neville, Liverpool.* 3409.]

1886. Newton, Henry Edward, 6 Bream's Buildings, Chancery Lane, London, E.C.

1888. O'Sullivan, Alfred Timothy, 13 Henrietta Street, Swansea.

1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]

1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.

1888. Peake, Robert Cecil, Cumberland House, Redbourn, near St. Albans.

1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield.

1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield.

1890. Perry, Edwin, 25 Side, Newcastle-on-Tyne.

1884. Phillips, Richard Morgan, 21 to 24 State Street, New York, United States. [*Sarita, New York.*]

1891. Pirrie, John Barbour, Barn Flax Spinning Mills, Carrickfergus, Co. Antrim, Ireland.

1891. Plant, George, Moseley Road School, Birmingham.

1891. Rankin, Thomas Thomson, Principal, Coatbridge Technical School and West of Scotland Mining College, Coatbridge.

1886. Raven, Henry Baldwin, Messrs. Hare and Co., Temple Chambers, Temple Avenue, London, E.C.

1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.

1891. Rochfort, Bertram, 1 Fowkes Buildings, Great Tower Street, London, E.C. [*Rochfort, London.*]

1891. Rowcliffe, William Charles, 1 Bedford Row, London, W.C.

1888. Rowell, John Henry, New Brewery, High Street, Gateshead.

1883. Sandham, Henry, Keeper, Science and Art Department, South Kensington Museum, London, S.W.

1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.

1890. Schofield, John William, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]

1891. Spencer, Francis Henry, Robinson Gold Mining Co., Johannesburg Transvaal, South Africa.

1878. Stalbridge, The Right Hon. Lord, 12 Upper Brook Street, Grosvenor Square, London, W.

1886. Stumore, Frederick, 34 Leadenhall Street, London, E.C.

1890. Taylor, John, 99 and 101 Fonthill Road, Finsbury Park, London, N.: and Stockport.

1884. Tilfourd, George, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1888. Tucker, Thomas, Messrs. Isaac Tucker and Co., Turk's Head Brewery, Gateshead.

1869. Varley, John, Leeds Forge, Leeds.

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

1891. Wiseman, Edmund, Cheapside and John Street, Luton. [*Wiseman, Luton.*]

GRADUATES.

1884. Adam, Frank, Sir W. G. Armstrong Mitchell and Co., Elswick, Newcastle-on-Tyne; and 89 Church Street, Stoke Newington, London, N.

1885. Addis, Frederick Henry, District Locomotive Superintendent, Rajputana Malwa Railway, Mhow, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1890. Alderson, George Alexander, 15 Broadgate, Lincoln.

1874. Allen, Francis, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent; and Roydon Lodge, Erith, S.O., Kent.

1882. Anderson, William, Locomotive Department, North Eastern Railway, Leeds.

1878. Appleby, Charles, Jun., 89 Cannon Street, London, E.C. [*Appleby's, London.* 1731.]

1883. Appleby, Percy Vavasseur, 22 Walbrook, London, E.C.]

1887. Ashby, Joseph Harrison, Dowlais New Furnaces, East Moors, Cardiff; and Ascot Heath, Berkshire.

1889. Ashford, John, Messrs. Carr and Ashford, Apollo Works, Blews Street, Newtown Row, Birmingham.

1886. Atkey, Albert Reuben, Corporation Water Works, Nottingham.

1890. Aubin, Percy Adrian, 29 St. James' Street, St. Helier's, Jersey.

1888. Bailey, Wilfred Daniel, India-rubber Gutta-percha and Telegraph Works, Casilla de Correo 1212, Buenos Aires, Argentine Republic.

1888. Barker, Eric Gordon, Guyse House, Oxton, R.O., near Birkenhead.

1889. Barrow, Arthur Robert Maclean, Locomotive Department, North Western Railway, Sukkur, India: (or care of A. M. Barrow, 13 Upper Maze Hill, St. Leonard's-on-Sea.)

1882. Barstow, Thomas Hulme, Manager, Kaihu Railway, Dargaville, Auckland, New Zealand.

1888. Bell, Alexander Dirom, The Woll, Hawick.

1884. Bell, Robert Arthur, Locomotive Department, South Indian Railway, Negapatam, India: (or care of Mrs. Bell, 30 Brompton Crescent, London, S.W.)

1890. Bell, William Thomas, Messrs. Robey and Co., 10 Kaiser Wilhelmstrasse, Breslau, Germany.

1880. Birkett, Herbert, care of Messrs. S. G. Sansinena and Co., Calle Peru 126, Buenos Aires, Argentine Republic: (or 62 Green Street, Grosvenor Square, London, W.)

1884. Bocquet, Harry, care of Arthur E. Shaw, Estacion Central, Buenos Aires, Argentine Republic: (or care of Mrs. Bocquet, 73 Eardley Crescent, London, S.W.)

1888. Boulding, Sidney, Messrs. Green and Boulding, 21 Featherstone Street, London, E.C.

1886. Bourne, Thomas Johnstone, Clyde Villa, Southborough, Tunbridge Wells.

1888. Bradley, Arthur Ashworth, Robinson Gold Mining Co., P.O. Box 787, Johannesburg, Transvaal, South Africa: (or care of Rev. Gilbert Bradley, St. Edmund's Vicarage, Dudley, Worcestershire.)

1887. Bremner, Bruce Laing, 33 London Road, Carlisle: (or Streatham House, Canaan Lane, Edinburgh.)

1878. Brooke, Arthur, Post Office, Otahuhu, Auckland, New Zealand: (or care of Miss Helen Brooke, Sunnymead, The Rise, Sidcup, S.O., Kent.)

1890. Brousson, Robert Percy, Messrs. Woodhouse and Rawson, Cadby Hall Works, Hammersmith, London, W.

1889. Brown, Arthur Selwyn, 43 Portsdown Road, Maida Vale, London, W.; and Sydney, New South Wales.

1880. Buckle, William Harry Ray, 11 Billiter Buildings, 49 Leadenhall Street, London, E.C.

1886. Budenberg, Christian Frederick, 25 Demesne Road, Whalley Range, Manchester.

1890. Burne, Edward Lancaster, 21 Great College Street, Westminster, S.W.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

1891. Butcher, Walter Edward, Locomotive Department, London Brighton and South Coast Railway, Brighton; and 17 Hamilton Road, Brighton.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1891. Buttenshaw, George Eskholme, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1889. Calastrenć, John Carlos, Locomotive Department, Midland Railway, Kentish Town, London, N.W.

1891. Caswell, Charles Henry, Wallsend Pontoon Co., Roath Docks, Cardiff.

1889. Challen, Walter Bernard, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1890. Chatwood, Arthur Brunel, Lancashire Safe and Lock Works, Bolton.

1891. Church, Harry, Ingeniero, para la Colonia San Gustavo, La Paz, Entre Rios, South America: (or care of George Church, Willington, Bedford.)

1890. Cleeves, John Frederick, Rotherham. [*Cleeves, Rotherham.*]

1885. Clift, Leslie Everitt, Fernbank, Pittville, Cheltenham.

1883. Clinkskill, Alfred Alphonse Rouff, Messrs. James Clinkskill and Son, 1 Holland Place, St. Vincent Street, Glasgow.

1889. Cook, George Norcliffe, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1888. Cox, Herbert Henry, Hillside, Falmouth.

1887. Crosland, Delevante William, 22 Royal Crescent, Kensington, London, W.

1891. Cutler, Samuel, Jun., Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.

1890. Davidson, Albert, Messrs. Hattersley and Davidson, Arundel Engineering Works, 14 and 16 Arundel Street, Sheffield.

1884. Dixon, John, Eastwood Villa, Lytham, near Preston, Lancashire.

1891. Douglass, Alfred Edwards, Trinity House, London, E.C.

1891. Drummond, Hawtrey Marks, care of Mrs. Drummond, 145 Bruntsfield Place, Edinburgh.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1891. Duncan, Martin Gordon, 27 Dafforne Road, Upper Tooting, London, S.W.

1891. Edwards, Herbert Francis, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1885. Edwards, Walter Cleeve, Assistant Engineer, Midland Railway, Greymouth, New Zealand.

1887. England, William Henry, 53 Hillary Street, Leeds.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1890. Garrett, Frank, Jun., Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.

1891. Gillatt, Thomas Stanley, North British Railway Works, Cowlairs, Glasgow.

1886. Grant, Percy, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1891. Gregory, Henry Hodges Mogg, Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1890. Hatton, Thomas Reginald, The Laurels, Kington, Herefordshire.

1889. Hayward, Robert Francis, Messrs. Crompton and Co., Arc Works, Chelmsford.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, P. O. Box 19, Portland, Oregon, United States.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1891. Hodgson, William James, 7 Clipstone Avenue, Nottingham.

1887. Hogg, William, Craigmore, Blackrock, Dublin.

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1884. Holt, Follett, Ferro Carril Buenos Aires y Rosario, Campana, Argentine Republic: (or care of Robert Hallett Holt, 3 Devonshire Terrace, Portland Place, London, W.)

1889. Hosgood, Thomas Watkin, 26 Brunswick Street, Swansea.

1891. Hosgood, Walter James, Locomotive Department, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Arthur Fayrer, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1889. Howard, Geoffrey, Britannia Iron Works, Bedford.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works Norwich.

1891. Hughes, Edward Sinclair Bremner, Ericstane, Helensburgh.

1890. Jones, Arthur Dansey, Locomotive Works, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1891. Jordan, Frederic William, 42 Wells Street, Mortimer Street, Cavendish Square, London, W.

1889. Joy, Basil Humbert, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1883. Lander, Philip Vincent, Lyndhurst, Hampton Wick, R.O., Kingston-on-Thames: (or care of W. W. Lander, Imperial Ottoman Bank, 26 Throgmorton Street, London, E.C.)

1881. Lawson, James Ibbs, Resident Engineer, New Zealand Railways, Invercargill, Otago, New Zealand.

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 89, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1883. Malan, Ernest de Mérindol, Hull and Barnsley Railway, Howden.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1889. Marshall, Frank Theodore, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1888. Marten, Hubert Bindon, Contractor's Office, Great Western Railway, Pangbourne, near Reading; and Pedmore, Stourbridge.

1886. Mattos, Alvaro Gomes de, 98 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1887. May, Harold Milton, Lakemead, Totnes.

1891. Mills, Matthew William, Moss Foundry, Heywood, near Manchester.

1867. Mitchell, John, Swaithe Hall, Barnsley.

1868. Moor, William, Ocean House, Hartlepool.

1878. Newall, John Walker, Suffolk House, Laurence Pountney Hill, London, E.C.

1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1883. O'Connor, John Frederick, 16 and 18 Exchange Place, New York, United States.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1881. Oswell, William St. John, 121 Calle Defensa, Buenos Aires, Argentine Republic.

1889. Paget, Edgar Lyon, Messrs. A. Paget and Co., Loughborough.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.

1887. Paterson, John Edward, Locomotive Engineer's Office, New South Wales Government Railways, Wilson Street, Eveleigh, Sydney, New South Wales.

1890. Philipson, John, Jun., Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne.

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1890. Powell, Frederick, York House, Malvern Link, Malvern.

1887. Price-Williams, John Morgan, Engineer's Office, Great Northern Railway, 7 York Road, King's Cross, London, N.

1884. Reynolds, Thomas Blair, 5 Great George Street, Westminster, S.W.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1889. Roope, Walter, Stisted, Badulla, Ceylon: (or care of Mrs. Roope, 27 Stafford Terrace, Kensington, London, W.)

1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.

1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.

1890. Sanders, Percy Henry, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.

1890. Saxelby, Herbert Raffaelle, Messrs. J. Copeland and Co., Poultney Street Engine Works, Dobbies Loan, Glasgow.

1881. Scott, Ernest, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]

1886. Silcock, Charles Whitbread, Wood House, Ely.

1887. Simkins, Charles Wickens, Jun., Amguri Tea Estate, Amguri Post Office, Sibsagar, Assam, India: (or care of Charles W. Simkins, The Lodge, Lowdham, near Nottingham.)

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1889. Smith, Henry Buckley Bingham, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow.

1891. Smith, Joseph Philip Grace, Polytechnic School of Engineering, 309 Regent Street, London, W.

1891. Snell, John Francis Cleverton, Messrs. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.

1883. Swale, Gerald, Ingfield, Settle.

1887. Tabor, Edward Henry, Fennes, Braintree.

1889. Tangye, Harold Lincoln, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1884. Taylor, Joseph, 19 Foskett Road, Fulham, London, S.W.

1884. Taylor, Maurice, 4 Rue la Boëtie, Paris.

1884. Templeton, Edwin Arthur Slade, 42 Boscombe Road, Shepherd's Bush, London, W.

1889. Treharne, Gwilym Alexander, Pontypridd; and Aberdare.

1891. Vaizey, John Leonard, Locomotive Works, Great Eastern Railway, Stratford, London, E.; and 6 Grove Crescent, Stratford, London, E.

1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.

1888. Waddington, Samuel Sugden, Langley Villa, 42 Colfe Road, Forest Hill, London, S.E.

1885. Wakefield, William Marsden, Buckingham House, Government Place, Calcutta, India.

1884. Walker, Ralph Teasdale, Fabrick Olean, Sitoebondo, Java: (or Kaliemaas, Alleyne Park, West Dulwich, London, S.E.)

1888. Waring, Henry, Engineer, Dublin Laundry Co., Milltown, near Dublin; and 40 Frankfort Avenue, Rathgar, Dublin.

1886. Wesley, Joseph A., Clarke's Crank and Forge Works, Lincoln.

1883. Westmacott, Henry Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Weymouth, Francis Marten, 33 Alfred Road, Acton, London, W.

1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 41 Trumpington Street, Cambridge.)

1889. Wigham, John Cuthbert, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1889. Willis, Edward Turnley, 99 Shooter's Hill Road, Blackheath, London, S.E.

1890. Wilson, Alexander Cowan, care of Wilson Hartnell, Benson's Buildings, Park Row, Leeds; and Osgathorpe Hills, Sheffield.

1889. Winkfield, Richard Ernest, Electric Light Department, Great Western Railway, Paddington, London, W.

1890. Winmill, Hallett, Engineer, Pigg's Peak Gold Mining Co., Swaziland, South Africa; care of E. Taylor, Barberton, Transvaal, South Africa: (or care of C. C. Winmill, 14 Hamfrith Road, Stratford, London, E.)

1887. Wrench, John Henry Kirke, 80 Bismark Court, Chicago, United States: (or care of E. M. Wrench, Park Lodge, Baslow, Chesterfield.)

1889. Wright, Howard Theophilus, 16 Great George Street, Westminster, S.W.

1890. Wright, William Carthew, General Post Office, Melbourne, Victoria: (or care of Dr. Gaskoin Wright, 253 Eccles New Road, Salford, Manchester.)

1888. Yates, Edward, Wolverton Road, Stony Stratford.

1891. Yerbury, Frederick Augustus, 17 Victoria Street, Westminster, S.W.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

AUGUST 1878.

INTRODUCTION.

Whereas an Association (hereinafter called "the existing Institution") called "The Institution of Mechanical Engineers" has long existed for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply, and the existing Institution consists of Members, Graduates, Associates, and Honorary Life Members, and is possessed of books, drawings, and property used for the objects aforesaid;

And whereas the Institution is formed for furthering and extending the objects of the existing Institution, by a registered Association, under the Companies Acts 1862 and 1867; and terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

NOW THEREFORE IT IS HEREBY AGREED as follows:—

CONSTITUTION.

1. For the purpose of registration the number of Members of the Institution is unlimited.

MEMBERS.

2. The subscribers of the Memorandum of Association, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who, being a Member of the existing Institution, shall agree to transfer his membership of the existing Institution, and all rights and obligations incidental thereto, to the Institution, and to be registered as a Member of the Institution accordingly.

4. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

5. The rights and privileges of every Member of the Institution shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

QUALIFICATION AND ELECTION OF MEMBERS.

6. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

7. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

8. Any person may become a Graduate, Associate, or Honorary Life Member of the Institution, who, being already a Graduate, Associate, or Honorary Life Member of the existing Institution, shall agree to transfer his interest in the existing Institution, and all rights and obligations incidental thereto, to the Institution.

9. The Institution may admit such other persons as may be hereafter qualified and elected in that behalf as Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: Provided that no Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

10. The qualification and mode of election of Graduates, Associates, and Honorary Life Members, shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

ENTRANCE FEES AND SUBSCRIPTIONS.

11. The Entrance Fees and Subscriptions of Members, Graduates, and Associates, shall be prescribed by the By-laws from time to time in force, as provided by the Articles: Provided that no Entrance Fee shall be payable by a Member, Graduate, or Associate of the existing Institution.

EXPULSION.

12. If any Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the list of Members, Graduates, or Associates, as the case may be, by the Council, at any time afterwards, and he shall thereupon cease to

have any rights as a Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: Provided always, that this regulation shall not be construed to compel the Council to remove any name if they shall be satisfied the same ought to be retained.

13. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the list of Members, Graduates, or Associates (as the case may be), and such person shall thereupon cease to be a Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

14. The first General Meeting shall be held on such day, within four months of the registration of the Institution, as the Council shall determine. Subsequent General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

15. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

16. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members of the Institution, specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members

of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

17. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every Member of the Institution, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

18. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

19. Twenty Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purposes of a Special Meeting.

20. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

21. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if

no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

22. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded, and by a poll when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman, and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: Provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

23. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: Provided that the Chairman may review his decision at the same Meeting if any error be then pointed out to him.

BY-LAWS.

24. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be added or substituted as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members at an Annual General Meeting, after notice of the proposed alteration or addition announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

25. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-

Presidents; and the first Council (which shall include Past-Presidents of the existing Institution) shall be as follows:—

PRESIDENT.

John Robinson	Manchester.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S.	Newcastle-on-Tyne.
Frederick J. Bramwell, F.R.S.	London.
Thomas Hawksley	London.
James Kennedy	Liverpool.
John Penn, F.R.S.	London.
John Ramsbottom	Manchester.
C. William Siemens, D.C.L., F.R.S.	London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S.	Manchester.

VICE-PRESIDENTS.

I. Lowthian Bell, M.P., F.R.S.	Northallerton.
Charles Cochrane	Stourbridge.
Edward A. Cowper	London.
Charles P. Stewart	London.
Francis W. Webb	Crewe.
Percy G. B. Westmacott	Newcastle-on-Tyne.

COUNCIL.

Daniel Adamson	Manchester.
John Anderson, LL.D., F.R.S.E.	London.
Henry Bessemer	London.
Henry Chapman	London.
Edward Easton	London.
David Greig	Leeds.
Jeremiah Head	Middlesbrough.
Thomas R. Hetherington	Manchester.
Henry H. Laird	Birkenhead.
William Menelaus	Dowlais.
Arthur Paget	Loughborough.
John Penn, Jun.	London.
George B. Rennie	London.
William Richardson	Oldham.
John C. Wilson	Bristol.

26. The first Council shall continue in office till the Annual General Meeting in the year 1879. The President, two Vice-Presidents, and five Members of the Council (other than Past-Presidents), shall retire at each succeeding Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree amongst themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

27. The election of a President, Vice-Presidents, and Members of the Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

28. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another, and the President or Members of the Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

29. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws the officers and servants of the Institution shall be appointed and removed by the Council.

30. The powers and duties of the officers of the Institution shall (subject to any express provision in the By-laws) be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

31. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three Members of Council shall form a quorum.

32. The Council shall acquire the property of the existing Institution, and shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

33. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A.) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B.) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C.) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D.) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E.) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F.) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

34. The Council may, with the authority of a resolution of the Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution.

35. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members of the Institution in General Meeting, shall be afterwards impeached by any Member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

36. A notice may be served by the Council of the Institution upon any Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to such Member, Graduate, Associate, or Honorary Life Member, at his registered place of abode.

37. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post, and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

38. No Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to such Member in the same manner as if he had had due notice.

By-laws.

(*Last Revision, January* 1890.)

MEMBERSHIP.

1. Members, Graduates, Associates, and Honorary Life Members of the existing Institution, may, upon signing and forwarding to the Secretary of the Institution a claim according to Form D in the Appendix, become Members, Graduates, Associates, or Honorary Life Members respectively of the Institution without election or payment of entrance fees.

2. Candidates for admission as Members must be Engineers not under twenty-four years of age, who may be considered by the Council to be qualified for election.

3. Candidates for admission as Graduates must be Engineers holding subordinate situations and not under eighteen years of age; and they may afterwards be admitted as Members at the discretion of the Council.

4. Candidates for admission as Associates must be gentlemen not under twenty-four years of age, who from their scientific attainments or position in society may be considered eligible by the Council.

5. The Council shall have the power to nominate as Honorary Life Members gentlemen of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings, but Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following: — for Members, M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Graduate, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. An Entrance Fee of £2 shall be paid by each Member, except Members of the existing Institution, who shall pay no Entrance Fee, and Graduates admitted as Members, who shall pay an Entrance Fee of £1. Each Member shall pay an Annual Subscription of £3.

10. An Entrance Fee of £1 shall be paid by each Graduate, except Graduates of the existing Institution, who shall pay no Entrance Fee. Each Graduate shall pay an Annual Subscription of £2.

11. An Entrance Fee of £2 shall be paid by each Associate, except Associates of the existing Institution, who shall pay no Entrance Fee. Each Associate shall pay an Annual Subscription of £3.

12. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

13. In the case of Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

14. Any Member or Associate whose subscription is not in arrear may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds. All compositions shall be deemed to be capital moneys of the Institution.

15. The Council may at their discretion reduce or remit the Annual Subscription, or the arrears of Annual Subscription, of any Member who shall have been a subscribing Member of the Institution for twenty years, and shall have become unable to continue the Annual Subscription provided by these By-laws.

16. No Proceedings or Ballot Lists shall be sent to Members, Graduates, or Associates, who are in arrear with their subscriptions more than twelve months, and whose subscriptions shall not have been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, GRADUATES, AND ASSOCIATES.

17. A recommendation for admission according to Form A in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members if the application be for admission as a Member or Associate, and by three Members if it be for a Graduate.

18. All Elections shall take place by ballot, three-fifths of the votes given being necessary for election.

19. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

20. The Elections shall take place at the General Meetings only.

21. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form B; but his name shall not be added to the list of Members, Graduates, or Associates of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form C in the Appendix.

22. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

23. A Graduate or Associate desirous of being transferred to the class of Members shall forward to the Secretary a recommendation according to Form E in the Appendix, signed by not less than five Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F if an Associate, and according to Form G if a Graduate; but his name shall not be added to the list of Members until he shall have signed the Form H, and, if a Graduate, shall have paid £1 additional entrance fee, and £1 additional subscription for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

24. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

25. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands

of the Secretary for current expenses. He shall be appointed by the Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

26. The Secretary of the Institution shall be appointed as and when a vacancy occurs by the Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

27. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

28. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council.

29. All books, drawings, communications, &c., shall be accessible to the Members of the Institution at all reasonable times.

30. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

31. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

32. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

33. The General Meetings shall be conducted as far as practicable in the following order :—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or, with the consent of the Council, by the Author.

34. Each Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member asks that this shall be done.

35. Every Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

36. The President shall ex officio be Member of all Committees of Council.

37. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

38. The Council shall present the yearly accounts to the Members at the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members.

39. Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

40. At any Meeting of the Institution any Member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being not under twenty-four years of age, and desirous of admission into the Institution of Mechanical Engineers, we the undersigned proposer and seconder from our personal knowledge, and we the three other signers from trustworthy information, propose and recommend him as a proper person to become a thereof.

Witness our hands, this day of

Members.

FORM B.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. In conformity with the rules, your election cannot be confirmed until the enclosed form be returned to me with your signature, and until your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM C.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM D.

As a of the Institution of Mechanical Engineers, I claim to become a of the Association incorporated under the same name.

Please register me as a

FORM E.

Mr. being of the required age, and desirous of being transferred into the class of Members of the Institution, we, the undersigned, from our personal knowledge, recommend him as a proper person to become a Member of the Institution of Mechanical Engineers.

FORM F.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature. If this be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant.

Secretary.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature, and until your additional Entrance Fee (£1) and additional Annual Subscription (£1) be paid for the current year. If these be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of Members of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

Institution of Mechanical Engineers.

PROCEEDINGS.

January 1891.

The Forty-Fourth Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 29th January 1891, at Half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members, Associates, and Graduates, had been opened by a committee of the Council, and that the following forty-three candidates were found to be duly elected:—

MEMBERS.

Henry Conrad Vandepoel Ahrbecker,	Sydney, N.S.W.
John Archbold,	Eastwood, Notts.
Walter Bagshaw,	Batley.
John Baynes,	London.
George Charles Beckwith,	Swansea.
Alfred William Bevis,	Folkestone.
Samuel Boswell,	Manchester.
Cameron William Harrison Brock,	London.
Thomas Clarkson,	London.
Thomas Daniels,	Manchester.
John Norman Dick,	Penang.
Douglas Holt Dickinson,	Monte Video.
James Clark Dickinson,	Sunderland.
Edward Wynne Donovan,	London.

CHARLES FREDERICK FULLER,	London.
GEORGE MACFARLANE GRAY,	Hong Kong.
GORDON HARRIS,	London.
JOSEPH HUTCHINSON HARRISON,	Malvern.
JOSEPH HENRY JUDD,	Brighton.
WILLIAM ROBERTSON LINDSAY,	Dundee.
THOMAS LOWDON,	Cardiff.
JEREMIAH EUGENE MATHEWSON,	Sheffield.
JOHN SCOTT RICHARDSON,	Peru.
HUGH JORWERTH ROBERTS,	Calcutta.
FRANCIS JAMES ROCHE,	Shanghai.
HAROLD SANDS,	Nottingham.
F. WALTER SCOTT,	London.
MILLIN SELBY,	Lille.
ALEXANDER SIEMENS,	London.
RALPH HART TWEDDELL,	London.
JOHN WALMSLEY,	Huddersfield.
CHARLES WATT,	Melbourne.
WALTER JAMES WEIGHTMAN,	Bombay.
JOHN HENRY WIDDOWSON,	Manchester.
JAMES EDGAR WIMSHURST,	London.
JOSEPH WROE,	Manchester.

ASSOCIATES.

JOSEPH BOND MORGAN,	Liverpool.
GEORGE PLANT,	Birmingham.

GRADUATES.

GEORGE ESKHOLME BUTTENSHAW,	Rotherham.
HARRY CHURCH,	Buenos Aires.
HAWTREY MARKS DRUMMOND,	Liverpool.
WALTER JAMES HOSGOOD,	Cardiff.
JOHN FRANCIS CLEVERTON SNELL,	London.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1891.

The Council have the pleasure of presenting the Members with their forty-fourth Annual Report, showing the progress of the Institution during the past year. They commence for convenience with the usual statistics of membership and financial position.

At the end of last year the number of names of all classes on the roll of the Institution was 1943, as compared with 1858 at the end of the previous year, showing a net gain of 85. During 1890 there were added to the register 159 names; against which the loss by deceases was 31, and by resignation or removal 43.

The additions to the list of Members include, as the President had the gratification of announcing at the Spring Meeting, the name of His Royal Highness the Prince of Wales, with whose consent the Council had the honour of electing him an Honorary Life Member of the Institution, in appreciation of the interest he has at all times manifested, and the official consideration and recognition he has bestowed, in connection with the works of Mechanical Engineers, as recently exemplified by his opening the Forth Bridge, the latest triumph of Mechanical Engineering.

The following twelve Transferences of Graduates to the class of Members have been made by the Council in 1890:—

Emerson Bainbridge,	Sheffield.
William Stanway Booth,	Swansea.
Edward Dawson,	Cardiff.
Charles Anthony Duvall,	London.
John Howell Hosgood,	Cardiff.
Joseph Whitworth Hulse,	Manchester.
Lucien Alphonse Legros,	London.
Joseph Letchford,	Melbourne.
William Theodore Lucy,	Oxford.
Warine Ben Hay Martindale,	London.

HERBERT PILKINGTON,	Newcastle, Staffs.
JOHN STUART ELLIS DE VESIAN,	London.

The following nineteen Deceases of Members of the Institution have occurred during the past year :—

DANIEL ADAMSON,	Manchester.
SAMUEL ANDERSON,	Westbury.
DAVID BANDERALI,	Paris.
ARNOLD BUDENBERG,	Manchester.
JOHN CLARKE,	Leeds.
WILLIAM CLARKE,	Gateshead.
NATHANIEL CLAYTON,	Lincoln.
ROBERT NIVIN COTTRILL,	Bolton.
WILLIAM JEREMIAH HALL,	Limerick.
RICHARD HODSON,	London.
JOHN SHAW LOYND,	Mexico.
JAMES MACILRAITH (Associate),	Glasgow.
THOMAS ROBSON,	Fence Houses.
PHILIP POWYS ROGERS (Graduate),	Warora.
DAVID ROLLO,	Liverpool.
JOSEPH TAYLOR,	Birmingham.
CHARLES WELLS,	Moxley.
JOHN RHYS WILLIAMS,	Rhymney.
THOMAS WILSON,	London.

Of these Mr. Adamson was a Member of the Institution from 1859, a Member of Council from 1876, and a Vice-President from 1885. He was a regular attendant at the meetings, and took the keenest interest in the Proceedings.

The following eighteen gentlemen have ceased to be Members of the Institution during the past year :—

ROBERT LANCELOT ALLGOOD (Graduate),	Humshaugh.
ARTHUR SYDNEY BURNETT (Graduate),	Horwich.
JOSEPH JOHN BUTCHER,	Wilmington, U.S.A.
LORENZO WILLIAM CROSTA (Graduate),	Nottingham.
EDWARD WYBURD FURRELL,	St. Louis, U.S.A.
HENRY GOOD,	Shanghai.
HUMPHREY HENCHMAN,	Sydney, N.S.W.
THOMAS WILLIAM HISD,	Nottingham.
WILLIAM THOMAS HOGG,	London.

JAMES HUMPHRYS,	London.
WILLIAM JOHNSON,	London.
CHARLES HENRY MOSER (Associate),	Natal.
HEDLEY OLIVER,	Birmingham.
SAMUEL SHARROCK,	Liverpool.
PATRICK STEWART-HAMILTON,	Brighton.
WILLIAM TIJOU,	London.
WILLIAM AUGUSTUS WHARTON,	Nottingham.
ALBERT WOOTTON,	Loughborough.

In addition to these there have been twenty-five Resignations of membership.

The Accounts for the year ending 31 December 1890 are now submitted to the Members (*see* pages 10–13), after having been passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £6,784 16*s.* 5*d.*, while the expenditure, actual and estimated, was £5,738 6*s.* 2*d.*, leaving a balance of receipts over expenditure of £1,046 10*s.* 3*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £34,308 4*s.* 9*d.*; and allowing £600 for accounts owing but not yet rendered, the capital of the Institution amounts to £33,708 4*s.* 9*d.*, of which the greater part, as seen from the balance sheet, is invested in Railway Debenture Stocks, registered in the name of the Institution. The certificates of the whole of the securities have been duly audited by the Finance Committee and the auditor. Among the receipts for the year is included the repayment of the Corporation Duty for the three years 1885–86, 1886–87, and 1887–88, amounting to £70 13*s.* 8*d.* The payment of this amount, claimed under the "Customs and Inland Revenue Act 1885," had been made by the Institution in 1887 under notice of appeal; and pending the settlement of the appeal then already made by the Institution of Civil Engineers, the payments for the subsequent years have remained in abeyance. Consequent upon the final decision of the House of Lords, given on 1st August 1890, the above payment has now been refunded by the Board of Inland Revenue. While congratulating the Members upon this result, the

Council are sure that the Members will join with themselves in cordial congratulations to the Institution of Civil Engineers upon this favourable termination of a suit so long pending.

The work of the Research Committees during the past year is represented in the Proceedings by the publication of the elaborate reports of Marine-Engine Trials. These have naturally involved a large expenditure of time for subsequently working out with the requisite care the voluminous mass of data, obtained by the numerous staff of observers who have been employed under the direction of the chairman, Professor Kennedy, in carrying out trials of such long duration.

The intended experiments on the friction of pivot bearings have been made under the direction of the Research Committee on Friction, of which the President is the chairman. The report on these experiments will be duly presented at the earliest opportunity.

The Council have much pleasure in recording their thanks to the several Donors of the contributions that have been presented to the Library of the Institution during the past year. These additions are enumerated in pages 14–23. Members are invited to present original pamphlets and records of experimental research, and other works valuable for reference; such contributions are always welcome for permanent preservation in the Library.

The General Meetings in 1890 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting in Sheffield; and the Autumn Meeting in London. Altogether nine sittings were occupied in the reading and discussion of the following Papers, which are published in the Proceedings:—

On the Compounding of Locomotives burning Petroleum Refuse in Russia; by Mr. Thomas Urquhart.

On the Burning of Colonial Coal in the Locomotives on the Cape Government Railways; by Mr. Michael Stephens.

On the Mechanical Appliances employed in the Manufacture and Storage of Oxygen; by Mr. Kenneth S. Murray, communicated through Mr. Henry Chapman.

Address by the President.

Research Committee on Marine-Engine Trials: Report upon Trials of three Steamers, "Fusi Yama," "Colchester," "Tartar"; by Professor Alexander B. W. Kennedy, F.R.S., Honorary Life Member, Chairman.

On Steel Rails, considered Chemically and Mechanically; by Mr. Christer P. Sandberg.

On recent improvements in the Mechanical Engineering of Coal Mines; by Mr. Emerson Bainbridge.

Description of the Parkgate Iron and Steel Works; by Mr. Charles J. Stoddart.

Description of the Loomis process of making Gas for Fuel; by Mr. R. N. Oakman, Jun.

Description of the Sheffield Water Works; by Mr. Edward M. Eaton.

On Tube-Frame Goods Wagons of light weight and large capacity, and their effect upon the Working Expenses of Railways; by Mr. M. R. Jefferds, communicated through Mr. Henry J. Marten.

On Milling Cutters; by Mr. George Addy.

The attendances during 1890 were as follows:—at the Annual General Meeting 74 Members and 37 Visitors; at the Spring Meeting 77 Members and 54 Visitors; at the Summer Meeting 278 Members and 77 Visitors; and at the Autumn Meeting 89 Members and 68 Visitors.

The Summer Meeting of the Institution was held in Sheffield, thanks to the readiness and energy with which the local Members and their friends, headed by the Mayor and the Master Cutler, responded to the wish of the Council that the Members should have an opportunity of appreciating the progress made during the interval of twenty-nine years which had elapsed since the previous meeting held there in 1861. Apart from the greater steel works, which have already for more than a quarter of a century been enhancing the world-wide renown of Sheffield by the ever increasing magnitude of their operations, the recent meeting has had the advantage of enabling the Members to realise how largely dependent upon mechanical engineering are the many other manufactures which are now vieing with one another in adding to the prestige of the town. The ancient cutlery manufacture, so vastly developed and improved since the time when it originally formed almost the sole industry associated with

Sheffield, is now reinforced by silversmiths' and electro-plating works, by the manufacture of engineers' tools and implements in great variety, and by engineering works both of general and of special kinds. Textile industry finds a representation peculiarly remarkable in the horse-hair cloth manufacture, wherein is seen the extraordinary degree of perfection to which automatic action can be carried in intricate processes of weaving previously performed by skilled hand-labour alone.

Three of the Papers read at the meeting were illustrated in a manner most acceptable to the Members present by visits to the works referred to. The comprehensive paper on Colliery Engineering, ranging over so extensive a variety of practical devices and appliances in which mechanical engineering is immediately concerned, was followed by excursions to the Nunnery Colliery and the Aldwarke Main Colliery, where many of the contrivances alluded to were seen in use, the working of these collieries having well kept pace with the progress of recent improvements. In the excursion to the Park-gate Iron and Steel Works, which embraced also visits to other engineering establishments situated between Sheffield and Rotherham, the description read at the meeting was supplemented by an inspection of one of the most recent examples of works laid out with the best modern appliances for the production of iron and steel on the large scale demanded by some of the present requirements. The visit to the Water Works covered the greater portion of the existing storage reservoirs and the gathering ground already utilised for the supply of Sheffield.

The handsome accommodation provided for the Meeting was due to the obliging invitations of the authorities of Firth College and of the Master Cutler; and the hospitalities of the Reception Committee were proffered in a variety of highly acceptable ways, including a Conversazione and the whole of the arrangements for the several Excursions. To the Honorary Secretaries, Professor Ripper and Mr. R. Heber Radford, on whom devolved the details of the entire arrangements, the Council have had the pleasure of presenting the cordial thanks of the Institution, engrossed upon vellum and framed.

In inviting the Members to contribute practical Papers on subjects of present interest in mechanical engineering, giving results of experience, and suitable for reading and discussion at the meetings of this Institution, the Council take the opportunity of making it known that the wall diagrams for the illustration of such papers as they may accept for reading and discussion will be prepared free of cost to the authors by the Institution drawing-office, to the extent of the time and accommodation available. The Council have also decided that the author of any paper published in the Institution Proceedings shall be presented with any number he may wish, not exceeding one hundred, of Excerpt Copies of his paper with discussion and engravings, as therein published; and that beyond the hundred he can be supplied at cost price with any further number of copies, if ordered before the printing of the Proceedings has taken place.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1890 . .	1,228	19	10			
Less Authors' Copies of Papers, repaid	8	13	0	1,220	6	10
„ Stationery and General Printing				180	6	9
„ Binding				21	14	1
„ Rent				700	0	0
„ Salaries and Wages				1,882	10	7
„ Coal, Firewood, and Gas				30	1	9
„ Fittings and Repairs				71	12	7
„ Postages				328	18	11
„ Insurance				5	8	1
„ Law Charges				16	16	0
„ Petty Expenses				43	17	3
„ Meeting Expenses—						
Printing	152	12	6			
Reporting	57	10	2			
Diagrams, Screen, &c.	74	4	9			
Travelling and Incidental Expenses	194	8	7	478	16	0
„ Dinner Guests				135	9	2
„ Research				604	5	2
„ Books purchased				18	3	0
				5,738	6	2
Accounts owing, not yet rendered, say	600	0	0			
Less Reserve in previous year for accounts since paid	600	0	0	0	0	0
Balance, being excess of Receipts over Expenditure, carried down				1,046	10	3
				£6,784	16	5

To Investment—			
£1082 *Metropolitan Railway 4% Debenture Stock*	1,399	0	9
To Office Furniture and Fittings	139	18	8
Cash Balance at this date	2,094	8	1
	£3,633	7	6

FOR THE YEAR ENDING 31ST DECEMBER 1890. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
128 *New Members at* £2	256	0	0			
10 *New Associates at* £2	20	0	0			
22 *New Graduates at* £1	22	0	0			
12 *Graduates transferred to Members at* £1	12	0	0	310	0	0
„ Subscriptions for 1890—						
1511 *Members at* £3	4,533	0	0			
55 *Associates at* £3	165	0	0			
133 *Graduates at* £2	266	0	0			
12 *Graduates transferred to Members at* £1	12	0	0	4,976	0	0
„ Subscriptions in arrear—						
81 *Members* at £3	243	0	0			
2 *Associates at* £3	6	0	0			
5 *Graduates at* £2	10	0	0	259	0	0
„ Subscriptions in advance—						
26 *Members at* £3	78	0	0			
1 *Graduate at* £2	2	0	0	80	0	0
„ Interest—						
From Investments	625	9	2			
From Whitworth Bequest	334	2	6			
From Bank	71	1	1	1,030	12	9
„ Corporation Duty 1885-6, 1886-7, 1887-8 refunded				70	13	8
„ Reports of Proceedings—						
Extra Copies sold				58	10	0
				£6,784	16	5

By Balance brought down	1,046	10	3
By Life Compositions, 7 Members at £50	350	0	0
Cash Balance 31st December 1889	2,236	17	3
	£3,633	7	6

Dr. BALANCE SHEET

	£	s.	d.
To Sundry Creditors—			
Accounts owing, not yet rendered, say	600	0	0
Capital of the Institution at this date	33,708	4	9
	£34,308	4	9

Signed by the following members of the Finance Committee:—

JOSEPH TOMLINSON,
SIR JAMES N. DOUGLASS,
ALEXANDER B. W. KENNEDY,
JOHN G. MAIR-RUMLEY.

AS AT 31ST DECEMBER 1890. *Cr.*

				£	s.	d.	£	s.	d.
By Cash—*In Union Bank, on Deposit*				1,200	0	0			
„ „ „ *on Current account* . .				394	8	1			
In Imperial Bank . . .	470	6	1						
In hand	29	13	11	500	0	0	2,094	8	1
„ Investments—(*cost* £18,888 9*s.* 3*d.*)									
£									
3,178 *London & North Western Ry.* 4% *Debenture Stock*									
2,200 *North Eastern*	„	„	„ „						
1,800 *Great Western*	„	„	„ „						
1,270 *Great Eastern*	„	„	„ „						
2,755 *Metropolitan*	„	„	„ „						
2,325 „	„	3½%	„ „						
1,000 *Aire & Calder Navigation*	„	„	„						
3,288 *Midland Railway*	3%	„	„						
700 *Sir J. Whitworth and Co., Ld.* 5%	„	„							
Two hundred £10 *shares Sir J. Whitworth and Co., Ld.*									
The Market Value of these investments at 31st Dec. 1890 *was about* . .							25,791	0	0
„ Subscriptions in Arrear £488, probable value							280	0	0
„ Office Furniture and Fittings							360	8	8
„ Library							1,230	0	0
„ Proceedings, back numbers at cost							4,450	0	0
„ Drawings, Engravings, Models, Specimens, and Sculpture .							102	8	0
							£34,308	4	9

Audited and Certified by

ROBERT A. McLEAN, Chartered Accountant,
1 Queen Victoria Street, London, E.C.

LIST OF DONATIONS TO LIBRARY.

Gas Engineer's Pocket Almanack; from Messrs. William Sugg and Co.

Description of the North Western Railway Bridge over the Indus at Sukkur; from the Director, North Western Railway.

Aeneidea (Vol. IV), by Dr. James Henry; from the trustees of the author.

Presidential Address to the Institution of Civil Engineers, by Sir John Coode, K.C.M.G.; from the author.

Report of the Kew Observatory Committee, 1889; from the Committee.

James Watt, and the Application of Science to the Mechanical Arts, by Professor Archibald Barr; from the author.

Compagnie des Chemins de fer de l'Est, Notices sur les Objets présentés à l'Exposition Universelle de 1889, Paris; from Monsieur Salomon, Ingénieur en Chef du Matériel et de la Traction.

Rules for Electrical Installations, compiled and adopted by the Victorian Institute of Engineers and the Fire Underwriters' Association of Victoria; from the Victorian Institute of Engineers.

Steel, its Manufacture, Properties and Uses, by James Riley; from the author.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 Dec. 1889; ditto to 30 June 1890; from the Registrar.

Interim Report on the Fruit Blights and Diseases of Fruit-Trees, by Professor T. Kirk; from the New South Wales Department of Technical Education.

Three Pamphlets (French) containing Extracts from the Bulletins de la Société des Anciens Élèves des Écoles d'Arts et Métiers, by N. J. Raffard; from the author.

Treatise on the Evaporation of Saccharine, Chemical, and other Liquids by the Multiple System, by James Foster; from the author.

The Works' Manager's Handbook, by W. S. Hutton (fourth edition); from the author.

Smokeless Explosives, by Sir Frederick A. Abel, C.B., F.R.S.; from the author.

School for Modern Oriental Studies established by the Imperial Institute; from Sir Frederick A. Abel, C.B., F.R.S.

Electrical Distribution of Energy over extended areas in Mines, by Albion T. Snell; from the author.

Lockwood's Builder's and Contractor's Price Book, 1890; from Messrs. Crosby Lockwood and Co.

Annual Report of the Chief of the Bureau of Steam Engineering, United States Navy Department, 1889; from the Bureau.

General Specifications for Iron and Steel Railroad Bridges and Viaducts, 1890, by Theodore Cooper; from the author.

Colliery Machinery, Inaugural Address at the Haydock Mining Lectures, by C. M. Percy; from the author.

Sinking Appliances at Llanbradach, by William Galloway; from the author.

Engineering Diagrams, by Thomas Jones; from the author.

The Mode of Occurrence of Coal, by William Galloway; from the author.

Isolement complet et stable des Machines, Véhicules, &c., by G. Anthoni; from the author.

La Carrosserie à l'Exposition Universelle de 1878, by G. Anthoni; from the author.

Map of the Japanese Seas, showing the tracks of the vessels of the Nippon Yusen Kaisha (Japan Mail Steam Ship Company); from Mr. William Barrie.

The Forth Bridge, reprinted from "Engineering," 28 Feb. 1890; from the proprietors of "Engineering."

Drawings of Rolling Stock on the East Indian Railway, designed and constructed at the Howrah Workshops, by Robert Webb Pearce, Carriage and Wagon Superintendent; from Mr. Richard Pearce.

Memorial to the Right Hon. Sir Michael Hicks-Beach, Bart., M.P., by the Manchester Steam Users' Association, on the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.

Handbook for Steam Users, by M. Powis Bale (third edition); from the author.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1890; from the Inspector-General of Chinese Customs.

Method of reducing the Fire Loss, by C. J. H. Woodbury; from the author.

Construction of Central Stations, by C. J. H. Woodbury; from the author.

La Thermodynamique et ses Applications aux Machines à Vapeur, by A. Madamet; from the author.

Chemins de fer d'Intérêt Local en France, by R. Doux; from the author.

Catalogue of Machinery, Models, &c., in the South Kensington Museum; with descriptive and historical notes by E. A. Cowper; from the Science and Art Department.

Final Report of Royal Commission to enquire into the Sanitary Condition of Melbourne; from the Royal Sanitary Commission, Melbourne.

Catalogue of Water-Tube Steam Boilers, &c.; from the Babcock and Wilcox Boiler Co.

The following official publications from the Government of New South Wales:—Statistical Register of New South Wales for 1888; Annual Reports of the Department of Mines for 1888 and 1889; Report of the Minister of Public Instruction for 1889; Papers in reference to Construction of Railway to Longnose Point; Report of Mr. William Thow on Condition of Rolling Stock; Report of Mr. R. Price-Williams on Condition of Permanent Way and Works of New South Wales Railways; Annual Statement

of Works carried out by Public Works Department during 1888; Australasian Statistics, 1888–9 (preliminary statement in part); Report on Dredging Operations (1888), by the Engineer-in-Chief for Harbours and Rivers; together with Reports on the following:—Proposed Drainage Works for the Western Suburbs of Sydney (with copy of Act sanctioning same); Proposed Improvements to the Entrance of Richmond River; Proposed Railway from Culcairn to Corowa; Proposed Railway from Goulburn to Crookwell; Proposed Railway to connect the North Shore Railway with Port Jackson at Milson's Point (second report).

Register of Fellows and Associates of the Institute of Chemistry of Great Britain and Ireland, 1890; from the Institute.

Sydney Technical College, Calendar 1890; from Mr. Norman Selfe.

Exposition Universelle Internationale de 1889: Congrès International des Procédés de Construction, tenu à Paris du 9 au 14 Septembre 1889; from Monsieur G. Eiffel.

Chronological, Historical and Heraldic Charts of the Royal House of England from King Egbert to the Present Time, by I. A. Timmis; from the author.

Annual Reports of the U.S. Chief of Ordnance, 1889 and 1890; from the Ordnance Office, Washington, U.S.

British Iron Trade Report, 1889; from Mr. J. S. Jeans.

Lindner System of Compound Locomotives; from Capt. Fairholme, R.N.

Efficiency of Gas Engines, by Thomas L. Miller; from the author.

How to Forecast the Weather months in advance, by Alfred J. Cooper; from the author.

Memoir of Horatio Allen, by M. N. Forney; from the author.

Cornell University Register, 1889–90 (second and third editions); from the University.

Facsimile of the Indenture of William Tongue's Apprenticeship to Messrs. Boulton and Watt, 5 Aug. 1797; from Mr. Richard B. Prosser.

Théorie cellulaire des Propriétés de l'Acier, by MM. Osmond and Werth; from Monsieur F. Osmond.

Essais sur le Magnetisme permanent des Aciers, by F. Osmond; from the author.

Nouveaux Procédés de Trempe, by F. Osmond; from the author.

Notes on the Construction of Ordnance; from the Ordnance Office, Washington, U.S.

In Darkest Africa, or the Quest Rescue and Retreat of Emin, Governor of Equatoria, by Henry M. Stanley; from Messrs. Clowes and Sons.

Borough of Ramsgate Front Improvements; from Mr. William A. Valon.

Notice nécrologique sur David Banderali (extract from Revue Générale des Chemins de fer, April 1890); from Monsieur E. Sauvage.

Electric Light Fitting, by John W. Urquhart; from Messrs. Crosby Lockwood and Co.

Effects of Training Walls in an Estuary like the Mersey, by L. F. Vernon-Harcourt; from the author.

Power Companies and Power Transmission by Compressed Air, by Norman Selfe; from the author.

Electrical Engineer's Pocket-Book, by H. R. Kemp; from Messrs. Crosby Lockwood and Co.

Magnetic Properties of Alloys of Nickel and Iron, by Dr. John Hopkinson, F.R.S.; from the author.

Boiler Explosions 1889, by Edward B. Marten; from the author.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Wattles and Wattle-Barks, by J. H. Maiden; from Mr. Norman Selfe.

Red-Hot Furnace-Crown Experiments; from Mr. Lavington E. Fletcher.

Technical Education, by Professor Robert H. Smith; from the author.

Human Beast of Burden, by Otis T. Mason; from the Smithsonian Institution.

Report on the section of Steam Transportation in the U.S. National Museum, 1886; from the Smithsonian Institution.

Le Chemin de fer Decauville pendant l'Exposition de 1889; from Monsieur Decauville.

Public Works Department Serials, from the India Office:—No. 18, Papers relating to Water-Supply Schemes in India, part I (Major Works); No. 19, ditto part II; No. 20, ditto part III (Minor Works); No. 23, Papers relating to the Orissa Coast Canal (second series); No. 24, Papers relating to the Khushdil Khan Reservoir Scheme; No. 25, Papers relating to the Kohima and Gauhati Water-Supply Schemes and the Mhow Water Works; No. 26, Papers relating to the Sangam Anicut Project.

Gold Fields of South Africa; from Mr. S. H. Farrar.

The Great Tower for London; from the Tower Co.

Experiments on Engines at the Copenhagen Water Works, by F. Ollgaard; from Mr. Bryan Donkin, Jun.

Presidential Address to the British Association for the Advancement of Science, Leeds 1890, by Sir Frederick A. Abel, C.B., F.R.S.; from the author.

Progress and work of the Institute of Patent Agents, by H. Howgrave Graham; from the author.

New form of Siemens Furnace, arranged to recover waste gases as well as waste heat, by John Head; from the author.

Electric Lighting and Fire Insurance Rules, by Wilson Hartnell; from the author.

Hardening and Tempering of Steel, by William Chandler Roberts-Austen, C.B., F.R.S.; from the author.

Calendar 1890–91, and second supplement of the Library Catalogue of the Royal Technical High School, Berlin; from the Rector.

Metallurgy of Silver, Gold, and Mercury in the United States, Vol. II, by Thomas Egleston, LL.D.; from the Proprietors of "Engineering."

Expériences sur le Frein automatique Westinghouse appliqué sur un train de 50 voitures entre Courtalain et Besse-sur-Braye; from Mr. Albert Kapteyn.

The following from Mr. Henry Chapman:—La Compagnie des Hauts Fourneaux, Forges et Aciéries de la Marine et des Chemins de fer (Saint-Chamond)—ses Travaux militaires, par F. Comportey; Note sur les Locomotives Compound, Chemins de fer de Paris à Lyon et à la Méditerranée, par Ch. Baudry; Fours de Verrerie à Pots et à Bassin chauffés au Gaz avec Chaleur récuperée; Fabrication du Gaz d'Éclairage, Fours de Distillation chauffés au Gaz avec Chaleur récuperée (système R. Radot et Lencauchez); Applications du Gaz en 1889, par Ph. Delahaye; Nouvel Éclairage par l'Electric-Gas, lumière simili-électrique sans électricité, par Georges Delaporte; Résistance des Matériaux, par A. Madamet; La Traction mécanique sur les Voies ferrées, par Léon Francq; Iron versus Wooden Cross-Ties for Railroads, by J. L. Weyers; Mémoire sur la Marche à Contre-Vapeur des Machines Locomotives, notice historique, par M. Le Chatelier; Roburite, the new safety Explosive; Note sur les Conditions générales de l'Étude des Machines marines, par M. Widmann; Appareils de Distribution par Tiroirs &c., par S. Pichault (with atlas of Plates); Notice sur les Types des Locomotives et des Voitures présentés à l'Exposition Universelle de 1889 (Société des Chemins de fer Italiens de la Méditerranée); Machine Locomotive à Grande Vitesse de 750 chevaux-vapeur, étudiée par Ala Béothy; Coin élastique en Acier, système David (two editions); The South's Redemption, from Poverty to Prosperity, by Richard H. Edmonds.

Calendars for 1890–91 from the following Colleges:—University College, Bristol; Glasgow and West of Scotland Technical College; Yorkshire College, Leeds; City of London College; King's College, London.

Essais sur les Chemins de fer de l'État Belge du Frein Westinghouse, appliqué aux trains de marchandises en Juillet et Août 1890; from Mr. Albert Kapteyn.

Re-determination of the True Weight of a Cubic Inch of Distilled Water, by H. J. Chaney; from the author.

Report on a proposed tramway from Landsborough to the Blackall Range, by George Phillips; from Mr. J. Alfred Griffiths.

Manifestation en l'honneur de G. A. Hirn; from Mr. Bryan Donkin, Jun.

Locomotive Development, by Clement E. Stretton; from the author.

Illustrated Catalogue of Steam Fittings, &c.; from Messrs. Brooks and Walker.

Description of the Witwatersrand Gold Fields, South Africa (with four coloured geological sections), by Thomas D. Williams; from the author.

Indications of Retrogression in Pre-historic Civilization in the Thames Valley, by H. Stopes; from the author.

Factors of Safety, by Thomas L. Miller; from the author.

Reports of the American Railway Master Mechanics' Association 1874–78, 1880–81, 1886–89; from Mr. J. Davis Barnett.

Conférence sur les Essais des Fers et des Aciers et les Laboratoires de Mécanique, by E. Cornut; from the author.

Recent developments in High Explosives, by Perry F. Nursey; from the author.

Fox's system of Solid-pressed Steel Wagon and Carriage Frames, by Perry F. Nursey; from the author.

Communication sur les Avantages de la Haute Pression de la Vapeur dans les Machines Compound, par A. Lencauchez; from the author.

La Production et l'Emploi de la Vapeur considérée comme Force Motrice principalement dans les Locomotives, par A. Lencauchez et L. Durant; from Monsieur A. Lencauchez.

Catalogue of Models illustrating Mechanism and the Elements of Machines in the Royal College of Science for Ireland; from Professor H. G. Hennessy.

Moteur à Gaz Simplex, Expériences faites sur un Moteur de cent chevaux indiqués, par A. Witz; from Monsieur E. Delamare-Debouteville.

Report of the Hydraulic Engineer on the Water Supply of Queensland; from Mr. J. B. Henderson.

Decimal Coinage, Weights and Measures popularly explained, by Sir Guilford Molesworth, K.C.I.E., and J. Emerson Dowson; from Sir Guilford Molesworth, K.C.I.E.

Scientific Papers of James Clerk Maxwell; from the Clerk Maxwell Memorial Committee.

Second Annual Report of the De Beers Consolidated Mines for year ending 31 March 1890; from Mr. Charles Cochrane.

Artesian Well at Charleville, Queensland (lithographed drawing); from Mr. J. B. Henderson.

Manufacture of Crucible Cast-Steel, by Henry Seebohm; from Messrs. Seebohm and Dieckstahl.

From the United States Geological Survey.

Seventh and Eighth (two parts) Annual Reports of the United States Geological Survey, 1885–86 and 1886–87, by J. W. Powell.

Bulletins of the United States Geological Survey, Nos. 48–57.

The following four Monographs of the Survey :—

XIII. Geology of the Quicksilver Deposits of the Pacific Slope (with Atlas), by George F. Becker.

XIV. Fossil Fishes and Fossil Plants of the Triassic Rocks of New Jersey and the Connecticut Valley, by John S. Newberry.

XV. The Potomac or Younger Mesozoic Flora (two parts, Text and Plates), by William Morris Fontaine.

XVI. The Paleozoic Fishes of North America, by John S. Newberry.

The following Publications from the respective Societies and Authorities :—

Reports of the Academy of Science, France.

Annales des Ponts et Chaussées, Paris.

Proceedings of the French Institution of Civil Engineers.

Journal of the French Society for the Encouragement of National Industry.

Reports of the French Association for the Advancement of Science, 1889.

Annales des Mines.

Journal of the Marseilles Scientific and Industrial Society.

Proceedings of the Industrial Society of St. Quentin et de l'Aisne.

Proceedings of the Industrial Society of the North of France.

Proceedings of the Industrial Society of Rouen.

Proceedings of the Industrial Society of Mulhouse.

Proceedings of the German Society of Engineers.

Reports of the Royal Academy of Science, Belgium.

Reports of the Royal Institute of Engineers, Holland.

Proceedings of the Engineers' and Architects' Society of Canton Vaud.

Proceedings of the Engineers' and Architects' Society of Austria.

Proceedings of the Engineers' and Architects' Society of Prague.

Proceedings of the Architects' and Engineers' Society of Hannover.

Proceedings of the Italian Engineers' and Architects' Society.

Proceedings of the Engineers' and Architects' Society of Milan.

Proceedings of the Russian Imperial Institute of Engineers.

Proceedings of the Swedish Society of Engineers.

Journal of the Norwegian Technical Society.

Journal of the Franklin Institute.

Transactions of the American Society of Civil Engineers.

Transactions of the American Society of Mechanical Engineers.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Report of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Engineering Association of New South Wales.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Chesterfield and Midland Counties Institution of Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Proceedings of the South Staffordshire Institute of Iron and Steel Works Managers, vols. 1–4.
Proceedings of the Royal Society of London.
Proceedings of the Royal Society of Edinburgh.
Proceedings of the Royal Institution of Great Britain.
Transactions of the Surveyors' Institution.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Journal of the Royal Agricultural Society of England.
Journal of the Royal Statistical Society.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions and Journal of the Royal Institute of British Architects.
Transactions of the Incorporated Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.

Transactions of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions and Proceedings of the Royal Irish Academy.
Transactions and Proceedings of the Royal Dublin Society.
Transactions of the Institute of Marine Engineers.
Journal of the Liverpool Polytechnic Society.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Proceedings of the Society of Architects.
Transactions of the Manchester Association of Engineers.
Report &c. of Ninth Session of the Junior Engineering Society.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Midland Steam Boiler Inspection and Assurance Company, Records of Boiler Explosions in 1884, 1885, and 1886; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.
Report of the London Association of Foremen Engineers and Draughtsmen.
Seventh Annual Report of the Barrow-in-Furness Free Public Library.
Thirty-seventh Annual Report of the Liverpool Free Public Library.
Thirty-eighth Annual Report of the Manchester Public Free Libraries.
Catalogue of Additions to the Radcliffe Library, Oxford, during 1889.

The following Periodicals from the respective Editors:—

Revue générale des Chemins de fer.
Revue universelle des Mines.
Revue industrielle.
Stahl und Eisen.
Der Civil-Ingenieur.
Glaser's Annalen.
Giornale del Genio Civile.
Ingeniero y Ferretero Español y Sud Americano.
The American Engineer.
The American Manufacturer.
The Engineering and Mining Journal.
The National Car and Locomotive Builder.
The Railroad and Engineering Journal.
The Railway Master Mechanic.
The Indian Engineer.
Indian Engineering.
The Engineer.
Engineering.
The Railway Engineer.
The Marine Engineer.
Iron.
The Iron and Coal Trades Review.
Ryland's Iron Trade Circular.
The Ironmonger.
Ironmongery.
The Mechanical World.

The Mining Journal.
The Colliery Guardian.
The Machinery Market.
The Builder.
The Electrician.
The Electrical Review.
The Chamber of Commerce Journal (from Mr. Henry Chapman).
The Contract Journal.
The Gas World.
The Plumber and Decorator.
The Shipping World.
The Steamship.
The Fireman.
Industries.
Invention.
The British Trade Journal.
The Practical Engineer.
Electrical Plant.
Mechanical Progress.
Hardware Trade Journal.

The PRESIDENT congratulated the Members upon the progress of the Institution during the past year, as shown by the Annual Report of the Council. The number of Members he trusted would continue to increase, as it had done during 1890. The Report and accounts spoke so plainly for themselves that it was needless for him to go into any details; and he would therefore simply move that they be received and adopted.

Mr. JEREMIAH HEAD, Past-President, had much pleasure in seconding the motion.

No Member offering any remarks, the motion was put to the Meeting, and agreed to.

The PRESIDENT announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected:—

PRESIDENT.

JOSEPH TOMLINSON, ...	London.

VICE-PRESIDENTS.

ALEXANDER B. W. KENNEDY, F.R.S., .	London.
E. WINDSOR RICHARDS, . . .	Low Moor.

MEMBERS OF COUNCIL.

ARTHUR KEEN, ...	Birmingham.
WILLIAM H. MAW, ...	London.
T. HURRY RICHES, ...	Cardiff.
WILLIAM H. WHITE, F.R.S., . .	London.
THOMAS W. WORSDELL, . . .	Arnside.

The Council for the present year will therefore be as follows:—

PRESIDENT.

JOSEPH TOMLINSON, ...	London.

PAST-PRESIDENTS.

THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., . . .	Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., .	Northallerton.
SIR FREDERICK J. BRAMWELL, BART., D.C.L., F.R.S., ...	London.
EDWARD H. CARBUTT, . . .	London.
CHARLES COCHRANE, ...	Stourbridge.
THOMAS HAWKSLEY, F.R.S., . . .	London.
JEREMIAH HEAD, ...	Middlesbrough.
JOHN RAMSBOTTOM, ...	Alderley Edge.
JOHN ROBINSON, ...	Leek.
PERCY G. B. WESTMACOTT, . . .	Newcastle-on-Tyne.

VICE-PRESIDENTS.

WILLIAM ANDERSON, D.C.L., . .	Woolwich.
SIR JAMES N. DOUGLASS, F.R.S., . .	London.
ALEXANDER B. W. KENNEDY, F.R.S., .	London.
ARTHUR PAGET, ...	Loughborough.
SIR JAMES RAMSDEN, ...	Barrow-in-Furness.
E. WINDSOR RICHARDS, . . .	Low Moor.

MEMBERS OF COUNCIL.

BENJAMIN A. DOBSON, ...	Bolton.
SIR DOUGLAS GALTON, K.C.B., D.C.L., F.R.S., ...	London.
JOHN HOPKINSON, JUN., D.Sc., F.R.S., .	London.
SAMUEL W. JOHNSON, ...	Derby.
ARTHUR KEEN, ...	Birmingham.
WILLIAM LAIRD, ...	Birkenhead.
JOHN G. MAIR-RUMLEY, . . .	London.
HENRY D. MARSHALL, . . .	Gainsborough.
EDWARD P. MARTIN, ...	Dowlais.
WILLIAM H. MAW, ...	London.
T. HURRY RICHES, ...	Cardiff.
BENJAMIN WALKER, ...	Leeds.
WILLIAM H. WHITE, F.R.S., . .	London.
J. HARTLEY WICKSTEED, . . .	Leeds.
THOMAS W. WORSDELL, . . .	Arnside.

The PRESIDENT thanked the Members of the Institution for re-electing him as their President for a second year of office. When elected a year ago he had promised to do his best for the benefit of the Institution, and to endeavour to carry on the work in an efficient and proper manner. This he had tried to do, and he hoped it might be inferred from his re-election that he had succeeded to the satisfaction of the Members. At any rate he was prepared, health permitting, to do his best during the present year, as he had endeavoured to do during the past year.

The PRESIDENT said it was his pleasing duty to announce that it had now been arranged for the Summer Meeting of the Institution to be held this year in Liverpool, in response to the following letter of invitation which had been received from the Mayor of Liverpool, who was taking a great interest in this matter and was a personal friend of his own :—

The Town Hall, Liverpool, W.
26 January 1891.

Dear Sir,

I have the pleasure of informing you that at a largely attended meeting, summoned by myself, of the leading engineers, shipowners, merchants, and other influential residents in this city and the neighbourhood, I have been requested to convey their cordial invitation to the Institution of Mechanical Engineers to hold this year's Summer Meeting of the Institution in Liverpool at the end of July. In this invitation I heartily concur.

I am, Yours truly,
JOSEPH B. MORGAN,
Mayor.

Joseph Tomlinson, Esq.,
President,
Institution of Mechanical Engineers.

The election of new Associates, already announced (page 2), included the name of the Mayor, who had been connected for a number of years past with the Telephone Co. of London ; and it was through his indefatigable exertions that the use of the telephone had grown to its present enormous extent in this city. It had been with him a sort of labour of love, and he had worked almost incessantly to bring it to a successful issue. As a director also of the various subsidiary telephone companies he had been instrumental in carrying out the telephone system all over Great Britain and Ireland. Under these circumstances the Council had considered that, while not himself a mechanical engineer, Mr. Morgan was so far associated with practical engineering as to be entitled to election as an Associate of this Institution ; and in the election which had taken place at the present meeting the Members had now ratified the opinion of the Council.

The PRESIDENT reminded the Members that at the present meeting the appointment had to be made of an Auditor for the present year.

On the motion of Mr. JAMES PLATT, seconded by Mr. EDWARD F. DANIEL, it was unanimously resolved that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year, at a remuneration of Ten Guineas, being the same as heretofore.

BY-LAWS.

Mr. J. MACFARLANE GRAY, in pursuance of the notice given at the previous General Meeting, proposed the following motion :—

"When the total annual subscriptions paid by any Member amount to thirty annual subscriptions of £3 each, he shall thereafter be declared a Life Member of the Institution, entitled to all the benefits of membership without any further payment to the Institution."

In going through the list of members he had been astonished to find that the number of those who had now been members of the Institution for thirty years or more was so great. According to the death-rate deduced from the deceases during 1890 which had been announced in the Annual Report of the Council, the average expectation of life seemed to amount to 102 years beyond the average age at election. The year 1889 was less favourable; but, taking these two years together, the average expectation after election appeared to be still over three score years and ten. The explanation of these high numbers was that only about one in three of the members continued their membership during life; and as the result of the passing of this motion would be to reduce the number of lapsing members, the funds of the Institution would be thereby benefitted as much as would make up for the creation of free life members. He had also in his mind that one young member, with apparently a distinguished future before him, who had been elected at the last meeting after being proposed by himself, and with whom he had talked over this motion, had been cut off before he had an

(Mr. J. Macfarlane Gray.)

opportunity of taking his seat amongst the members; he referred to the late Mr. Peter Borrie Blair of Stockton-on-Tees.

In advocating this change in the rules, he was not forgetting that some of the most distinguished members dated from the formation of the Institution in 1847. They had therefore paid forty-four annual subscriptions; and it would not be possible to rectify to them the inequality of payments which the rule he was now seeking to establish was intended to mitigate. He knew that the original members still had the good of the Institution at heart, and he counted upon their support. According to the wording of the motion he wished it to apply even to lapsed membership. He had heard of some members who under temporarily unfavourable circumstances had ceased to be members. If any such there were who would now be inclined to rejoin the Institution, he would say that their total subscriptions ought to be counted in to make up the limit of £90. In bringing this motion forward, he was actuated merely by the belief that it was a reasonable arrangement, and that it had only to be put before the members to be at once accepted. He had taken no step outside to get support, and had asked no member to vote for it. If any member had another plan to propose, it would be quite in order to introduce an amendment to that effect now; for he had intimated at the previous meeting that his motion was intended to indicate a principle only, and that the number of years or any other detail in the proposal might be modified during the discussion at the present meeting. It might be said that the alteration was not required, seeing that a new rule had been made only two years ago (By-law 15), empowering the Council at their discretion to reduce or remit the annual subscription or the arrears of subscription of any member who had been a subscribing member of the Institution for twenty years and had become unable to continue his subscription, provided of course that the Council thought the case a proper one to be so dealt with. During the discussion of that rule (Proceedings 1889, page 30) he had endeavoured to introduce a twenty-five years' limit of full subscription, and after that limit a reduced annual subscription of only £1. His view had been then, and was now, that reduced subscription or life privilege ought to be

entered upon by right, and not alone by favour, by all who had paid for a certain term of years. He did not wish however in the slightest degree to question the wisdom or the propriety of the new rule then passed; its application was an honour to the life member and a credit to the Council. Other members, who like himself did not presume that they had any likelihood of meriting the special favour of the Council to that extent, might have good reasons for desiring that the annual calls upon them should be diminished as their age increased. He had been informed of one instance, in which a member, who thought the proposal of a reduced subscription suited his own circumstances, had represented that he felt himself unable to continue the full subscription, and was anxious to retain his membership; and as he had already paid thirty-one annual subscriptions, he hoped the Council would allow him to continue his membership by an annual payment of £1. To this application the Council had not acceded, and they had declined to accept his resignation unless he remitted the £2 balance of his subscription before the end of the year then current, pointing out that if he did not he would become liable also for the subscription for the following year. The member considered that his means did not justify his doing so. He had not received any further proceedings since the end of that year, although, having paid an instalment of the year's subscription, he was at the time only eight months in arrear. After thirty-one years' membership the only side of the story to be considered ought to be that which the member felt it his duty to represent. He therefore thought that, notwithstanding the new rule passed two years ago for the remission of subscriptions at the discretion of the Council, a further alteration was still required, such as was embodied in the motion now proposed.

Mr. ROBERT BRUCE had much pleasure in seconding the motion. In view of the fact that the capital of the Institution now amounted to £33,000, he thought it would be desirable to stretch a point in consideration of the talent and ability which might have been imported into the proceedings by those who had been members for the thirty years mentioned in the motion.

Mr. E. WINDSOR RICHARDS, Vice-President, was strongly in sympathy with the motion proposed. Any one who had been a consistent and useful member of the Institution for thirty years he thought should then be entitled to become free from all further subscription. Such a motion if carried he believed would strengthen the Institution. Members who might now sometimes hesitate about remaining after they had been connected with the Institution for twenty years would then decide to continue their membership, because they would reflect that in a few more years they would become free from further subscription. It might be that to some the subscription would not matter much from a monetary point of view; but there were others who could not altogether consider it in that light. The Institution was not poor; they had already more than £25,000 invested. What was going to be done with this money? By and by no doubt they would have a house of their own; but it would be some time hence. The Report of the Council showed a net increase during last year of eighty-five in the number of members. Supposing there were to be a loss, as had been made out by the Secretary, of about £240 in the present year through the subscriptions ceasing of those who by the proposed motion would be released from payment, yet the increase of members alone would make up that deficit. The members he thought would be justified in passing this motion, when they considered that they had now had a rule in force for the last year (By-law 14), whereby members on payment of £50 as a composition were exempt from further subscription.

Mr. J. F. L. CROSLAND observed that on page 4 of the Annual Report it was stated that certain gentlemen had "ceased to be Members of the Institution during the past year"; and on page 5 it was further stated that in addition to these there had been a certain number of "resignations of membership." He asked what was the distinction between ceasing to be a member and resignation of membership.

Mr. J. HARTLEY WICKSTEED, Member of Council, noticed that the motion proposed was worded as having reference to any *Member*

whose total subscriptions amounted to thirty annual subscriptions of £3 each, that is £90. Was the term "member" used by the proposer in a general sense as denoting any one whose name was on the roll of the Institution, whether as a Member, or as an Associate, or as a Graduate? or was it used as meaning strictly a full member who had paid £3 during every year of his membership, so that it would not extend to graduates who prior to becoming full members had paid an annual subscription of £2 for several years? While himself fully in sympathy with the motion, he should prefer that it should be confined to those who had been full members for thirty years and had paid the full membership subscription, of course without any default in the regular payment. Irregularity in the proper observance of the rules concerning resignation of membership gave a great deal of unnecessary trouble; and he thought therefore in the retrospective application of such a privilege as was contemplated by the present motion it would not be practicable to include those members who had been in default with their subscriptions, at any rate until that default was made good up to the time of formal resignation. The distinction about which Mr. Crosland had asked, between resignation and cessation of membership, was the wide difference between a resignation duly given in conformity with the agreement signed by every member on his election, and a lapse of membership which took place simply because after repeated applications the subscription owing was not found to be forthcoming. When such default had continued for two years, the name was struck off the roll of the Institution, in accordance with the articles of association, and the membership ceased.

Mr. JAMES PLATT presumed it would still be optional for a member to continue his subscription if he chose, even after he might have come within the operation of the motion, supposing it to be carried.

The PRESIDENT thought any such option was hardly contemplated in the motion proposed.

Mr. J. F. FLANNERY considered the motion was right in principle. Although it might be said that any one who for thirty years had continued to enjoy the full benefits of membership owed something to the Institution, yet on the other hand he thought that a member who had continued in the Institution for so long deserved well of it; and such an honour as was proposed by the present motion would be highly appreciated, even quite apart from the remission of what after all was not a large annual payment.

Mr. BENJAMIN A. DOBSON, Member of Council, also cordially supported the motion. This was not a commercial Institution; and provided it could pay its way and keep everything straight, it was doing as much as could be expected. The average age of members on joining the Institution he imagined would be rather over thirty than under. If therefore a member had paid his subscription for thirty years, he would have arrived at an age when if he had not retired from business he might be expected to be thinking about doing so: although fortunately there were many members of this Institution who had considerably exceeded that limit, and were still actively engaged in engineering matters. The society of such members was more valuable to the Institution than their subscriptions. He could not agree with Mr. Wicksteed that a graduate's subscriptions prior to his transference to membership ought to be excluded from the calculation of the total amount contemplated by the motion. One object of the Institution was to attract as many young engineers as possible to join as graduates, with a view to their becoming members in future; and he thought it would not be fair to leave out of account the amount of subscriptions they might have paid as graduates. Such matters of detail however, which would require more careful consideration, might be left to the Council to deal with afterwards, if the principle were accepted of the motion proposed. Although the loss which would be immediately incurred by the passing of the motion was estimated at the sum of £240 for the present year, he was inclined to think that during the ensuing ten years it would be found not to exceed £100 a year. The question however was a complicated one, coming rather more

within the province of an actuary; and he was not able to go into it closely himself. The motion if carried he considered would confer an honour upon members who had been so long in the Institution; and the fact of their becoming honorary members as a matter of right which they had earned for themselves would even increase the value of the honour.

Mr. JEREMIAH HEAD, Past-President, while inclined to support the motion, thought it undesirable for the discussion to terminate without looking just a little at the other side of the question. Reference had been made to the fact that the Institution was somewhat wealthy, having a capital of more than £33,000; and the question had been asked, what were they going to do with that capital? There was a desire in the minds of a great number of the members that they should have a house of their own some day; and no doubt a great deal more than £33,000 would be required before this desire could be realised. Whether the motion now proposed were passed or not, he hoped that so desirable an object would be accomplished sooner or later. The immediate question now under consideration was however not so much one of capital as of income. The surplus of income in excess of expenditure had for some years past amounted to about £1,000 a year; last year it was seen to be £1,046, besides which there were life compositions of £350 carried to capital, making a total of £1,400, which sum the Council had already arranged to invest. It was estimated that the loss which would ensue upon carrying the motion would amount to something like £240 in the present year. Hence the probability was that, if the motion was carried, the saving in the present year would be £240 less than if it was not carried. There was therefore this other view of the question to be considered; and if the members passed the resolution, they must be prepared to face diminished savings. The question was whether the revenue would really recoup itself from that loss, by aid of the stimulus which the motion would give to longer membership. He looked upon the motion as offering a premium on long-continued membership; it would in fact confer a new privilege on members, that is, their subscriptions would entitle them

(Mr. Jeremiah Head.)

to something they had not had before. That would no doubt have the effect of stimulating many, who joined for a few years and then retired, to remain on for the thirty years. The principle was similar to that of compounding for life membership. As had been pointed out by Mr. Richards, a member could now compound by a payment in advance of £50, or nearly seventeen years' subscription. The average age of a member on joining the Institution had been taken by Mr. Dobson at something more than thirty. Supposing it were taken at forty, then by the ordinary rule the expectation of life at that age would be twenty-three years. Therefore the payment of seventeen years' subscription in the form of a life composition of £50 at the age of forty might be looked upon as entitling to a membership of twenty-three years. Instead of £50 down, a payment of £90 spread over thirty years was the alternative proposed in the motion now brought forwards. There was therefore no startling novelty in the proposal; and even if it entailed some loss to begin with, it conferred at the same time a new privilege, which he thought would make the Institution yet more popular than hitherto. It would tend to induce members to stick closer to their membership, and he did not think there would ultimately be any harm done. He therefore thought he should record his own vote in favour of the motion.

Mr. HENRY D. MARSHALL, Member of Council, quite agreed with the principle of the motion, and also with Mr. Wicksteed in hoping it would be confined to full members, so that only a full member who had paid the full subscription for thirty years should become a life member of the Institution. If the motion were to include graduates, he thought it would open a loop-hole which might be really detrimental to the Institution. Such a boon conferred on members who had continued in the Institution for thirty years would tend to popularise the Institution; and the effect of the immediate pecuniary loss would thereby be minimised. The latter however was a financial question; and therefore if the principle of the thirty years' full subscription were adhered to, and it were then left to the Council to carry out its application on that basis, he thought the motion would benefit the Institution.

Mr. J. F. L. CROSLAND thought the remarks made by Mr. Dobson had put the whole matter into a position in which it could be settled as a pure question of finance. Looking at the subject from an actuarial point of view, an annual premium of about £3 paid to a life insurance society by a person commencing at any age from twenty-five to thirty would insure £100 at the age of sixty. Clearly therefore it was only necessary to take the actual sum received from a member during thirty years, and to make the calculation purely at a life insurance rate, in order to decide whether that amount would be equal to the £50 down, which already enabled a member to compound for future payments. Without having gone into the figures, he considered that a subscription of £3 per annum for thirty years would be more than equivalent to the payment of £50 down. When looked at in this way, the motion now proposed he thought would be found a safe one for the financial interest of the Institution.

Mr. BENJAMIN WALKER, Member of Council, did not agree with the motion proposed. It was entirely a question of money value to the Institution. There would be a certain immediate loss by the arrangement; and he believed it would prove to be no practical advantage to the Institution. For he thought that comparatively few members discontinued their connection with the Institution because of poverty. But it was not unfrequently the case that riches, leading to retirement from active business pursuits, led also to diminution of interest in the Institution and to resignation of membership, notwithstanding ample means to continue the subscription. The amount of the subscription was simply a question of commercial arrangement, and was now working well, and he considered that there was no need to alter it. If there was any one who deserved to continue a member of the Institution, and the Council were satisfied that he had not the means to continue paying his subscription, they were empowered by the by-law passed two years ago to let him continue to receive the benefits of the Institution as a member without payment. The Institution had to be carried on by labour of various kinds; and every one knew how almost all kinds

(Mr. Benjamin Walker.)

of labour involved a greater cost now than at any former period. If the present motion were passed, the Institution would be going to reduce its income in the face of continually increasing work and expenditure; that was not the way to get rich enough for obtaining a house of their own. At the present time the accounts showed that about £1,400 a year was being carried to capital; but much more than that amount would have to be put by annually, if it were really intended ever to have a house of their own for the Institution. If this was to be an Institution large enough to influence the world in mechanical engineering, it must be far bigger than it was now. Whatever was done therefore, he urged the members not to let the income of the Institution be reduced. If the adoption of the motion proposed would entail an immediate loss of more than £200 a year, then by all means he would advise that no such arrangement should be made.

Mr. JOSEPH ADAMSON did not agree with the alteration aimed at by the motion proposed; he did not see any necessity for it. The by-law passed two years ago enabled any member who was unfortunate in after life to ask that his subscription might be remitted; and he was quite of opinion that in any such case of real misfortune the amount of sentimental feeling involved in asking the Council to remit the subscription until better times would be very small indeed. He quite agreed with Mr. Walker that the expenses of the Institution were likely to increase, independently of having any place of meeting of their own. They had a Research Committee, whose expenditure was shown in the yearly accounts; and although some of the members might not find it convenient to give a large subscription, still they would do far more good by contributing their share to help forward what they all lived by, than by accepting a remission of their subscription after a term of years. If the income of the Institution were reduced, he was quite sure its power of usefulness would be reduced, and also the power of maintaining its present position. So far from looking forwards to a remission of his subscription after thirty years' membership, he thought that any one who like himself had already been a member for twenty years

should rather be hoping that certainly after another ten years he would be much better able to pay his subscription than he had been when he joined the Institution. If any alteration were to be made, he should prefer some arrangement whereby young members could come in at a lower subscription, and that their subscription should be increased as they got older. Notwithstanding that the motion proposed had already been so well supported, he should himself vote for its rejection.

Mr. JAMES PLATT asked whether the case referred to by Mr. Macfarlane Gray had occurred before the by-law of two years ago had been passed for enabling the Council at their discretion to remit the subscription of a member unable to pay; or whether it was a fact that the by-law did not apply to that case for some reason or other.

Mr. J. MACFARLANE GRAY replied that the Council had declined to apply the by-law in the instance referred to, which had occurred subsequently to the passing of the by-law.

Mr. EDWARD F. DANIEL asked whether any case had yet occurred of a subscription being remitted in virtue of the by-law.

The PRESIDENT replied in the affirmative.

Mr. DAVID JOY thought the motion proposed would be a benefit to the Institution, rendering it more popular, and inducing more members to join; and that the loss on members coming within the range of the time of exemption would not be nearly so large as it appeared in figures, inasmuch as most of such members, old and well-tried friends of the Institution, while appreciating the courtesy proffered, would decline to avail themselves of the small money advantage. But there was another point which seemed not to have been taken into consideration. The subscription to this Institution being only £3 appeared a small matter; but there were no doubt others like himself, who were members of a number of other institutions, the item of subscriptions thus mounting up to a

(Mr. David Joy.)

substantial sum. In making a selection, the preference would naturally be given to those institutions offering the greatest advantages. It therefore appeared to him advisable to render the Institution as popular as possible, and so to make it to the interest of engineers not only to join it but to stand by it.

Mr. CHARLES E. COWPER asked whether any idea had been formed as to the prospective loss of income likely to attend the proposed motion if carried. An estimate had been mentioned by Mr. Richards that the result would be a loss of £240 on the income of the Institution in the present year. But had it been calculated what the loss would be ten years hence? He imagined it would be an increasing loss, and would perhaps represent an increasing percentage of the income.

The PRESIDENT replied that it seemed likely to be an increasing amount, so far as could be foreseen at present.

Sir JAMES N. DOUGLASS, Vice-President, said that, ever since this matter had first been brought forward by Mr. Macfarlane Gray more than two years ago, he had himself given it frequent and serious attention; and he was sure that every member would give it the consideration it deserved, as it was a matter of very great importance to the Institution. If he were to give way wholly to sentiment, he should go entirely with Mr. Gray, not altogether because he was an old friend, but because he had put the matter so earnestly, both on a former occasion and now again at the present meeting, that he was himself almost ready to follow him implicitly. The members had to consider however in the first instance what were the best interests of the Institution. Its present work could not be carried on without a large expenditure; and as the work was year by year increasing, the expenditure was naturally increasing also. Moreover it must not be forgotten that the innovation now proposed was a complete novelty. The Institution of Civil Engineers had no provision of the kind; and one of the causes which contributed largely to the success of that Institution was its accumulated wealth.

Why should not the Institution of Mechanical Engineers also have a house of their own? There were many wealthy members who he knew would come forward and assist as soon as ever the matter was fully ripe. Hitherto the Council had perseveringly been trying to ripen it for a number of years; and although they had not yet accumulated funds sufficient for the purpose, they could not see why they should not persevere. It was simply the support of their members which had enabled the Institution of Civil Engineers to provide themselves with a house affording the accommodation they required; and the same would hold good in regard to the Institution of Mechanical Engineers. Even if the motion now proposed were made into a by-law, he should feel for his own part that he could not accept the provision it embodied, so long as he could afford to continue the payment of his subscription. He was happy to know that he could express the feelings of his colleagues during the time that he had been on the Council with regard to members who were not able to pay. Since the Council had been empowered by the by-law passed two years ago to remit a subscription under such circumstances at their discretion, every case like that referred to by Mr. Gray had been carefully considered, with every possible disposition in its favour so far as was believed to be consistent with the regard due to the interests of the Institution; and he was sure the Council had gone as far as they felt themselves supported by the by-law. Having himself every regard for the proposer of the present motion, and every sympathy with the feeling which had prompted him to bring it forwards, he nevertheless hoped the members would not accept it.

Mr. A. C. BAMLETT concurred in opposing the motion. It appeared to him to have a twofold object: to give relief to members, which, so far as he could gather, they did not require unless only in exceptional cases; and to do honour to members who had been in the Institution for a great number of years. In regard to the latter, it might be possible he thought to find some other means of doing more honour to such members, in a way which would be quite as effective and as highly appreciated as remitting the payment of their subscriptions.

Mr. C. F. ARCHER said that as a young member it would be twenty-eight years before he should have the benefit of the proposed motion if it were carried. He should therefore prefer to support the suggestion made by Mr. Adamson, that young members should have the benefit of joining the Institution at a lower subscription. At the same time he thought that if any member now young imagined he should be likely at fifty-five or sixty years of age to find himself not able to pay £3 subscription, he had better throw up engineering at once and try something else. He had joined the Institution with the object of profiting by what he heard at the meetings, and by reading the Proceedings, so as to enable him to get on in his business; and he believed there were many young men who would be willing to join, if they could do so at a lower subscription. Such an arrangement he thought would increase the number of members not only now but in the future.

Mr. BENJAMIN BROWN pointed out that there was another way in which it was necessary to look at the loss of income which the Institution would sustain if the motion now proposed were carried. If the estimated loss of £240 were capitalised at 3 per cent., it would amount to about £8,000, and would be equivalent to reducing the capital of the Institution to that extent.

The PRESIDENT had listened with great interest to Mr. Gray's appeal to the generosity of the Institution. As one of the oldest members now present, he must say he had a strong feeling like Sir James Douglass that he could not accept the remission of his subscription after the thirty-four years which had now elapsed since he joined the Institution. For himself he would rather retire than accept the favour proposed; he did not like favours, and he thought the members generally had a sufficient spirit of independence to agree with him in not liking favours. As to the instance referred to by Mr. Gray of inability to continue payment of the subscription, he was sorry to say he did not agree in the inability alleged. It seemed to him that the very principle of the motion proposed was rather untenable. The tenant of a house had to continue paying the rent as

long as he remained the tenant; after he had rented it for thirty years, the landlord did not let him thenceforth live in it rent free. Therefore he thought there was not much in the argument founded upon length of membership. Moreover there were some of the richest members of the Institution who would come under the operation of the motion. And of those who had resigned their membership since he himself came upon the Council eleven years ago, the majority he believed had not resigned from impecuniosity, but were as well able to pay the subscription now as they were before they resigned. Looking at the efforts which the Institution was now making by their Research Committee to enlarge engineering knowledge, and also at the desire so frequently expressed that they should soon have a house of their own, he certainly thought it would be unwise to take a step which might endanger either of these objects. The capital of the Institution was now £33,000, and they were paying £700 a year rent for their offices; the two taken together seemed to him to give confidence that before much longer they might be able to build a house of their own. They were now asked to give up £240 this year; how much greater the loss might be in the following years he did not know exactly, because it would depend upon the death-rate. The latter he was glad to know was considerably below the average; whence he hoped it might be inferred that a longer membership was to be anticipated than would otherwise be the case. In support of the motion proposed, some curious letters had been received: in certain cases the thirty years of membership had already been completed; while in others a shorter term was recommended, such as would just suit the present length of the writers' membership. Support of that kind he thought could hardly be regarded as genuine; and he hoped such considerations would not influence the decision of the members now present. Under existing circumstances he certainly should not vote for the motion, because he considered it would hamper the Institution in what they had laid themselves out to do by means of their Research Committee, as well as in other ways. During his presidency they had spent more than £600 last year in research; and if they went on to spend another £600 in the present year he thought their money would be

(The President.)

much better spent in that way for the benefit of their profession than by returning it into the pockets of a few waverers; the majority of the members he believed would not care at all after thirty years' membership to accept a remission of their annual subscription.

Mr. J. MACFARLANE GRAY in reply said he had brought this motion forwards, as he had already stated, because he thought the arrangement proposed was reasonable; and he knew of many cases where it would be suitable and just. Not having agitated in any way to get support for the motion, he had not felt as a partisan with respect to it. In regard to the estimate of loss consequent upon the passing of the motion, he did not even take so favourable a view as was represented by the estimate which had been mentioned by members of the Council; but he confessed that what had been said against the motion had certainly made him now a little more of a partisan in its favour. The proposal had been spoken of as an appeal to the generosity of the members. Yet so far was this from being his own intention, that on the contrary it was from the objection which he had to appeal to their generosity that he had been led to propose a rule which should apply to all the members of the Institution alike. It was true that after twenty years the subscription of any member who had become unable to continue it could be remitted by the Council if they thought fit. Therefore any member requiring that remission had to apply to the Council; and, as was shown by the instance to which he had referred, it would not be sufficient merely to state that he considered himself unable to pay, but it was necessary that the Council should be satisfied of his inability. Such a mode of procedure seemed to him most undesirable; and he therefore preferred that after a certain number of years every member should be entitled to the privilege embodied in the motion now proposed.

In regard to Graduates, he had thought of adding a clause to the motion for expressing that they were to be included in its principle, as well as Associates also; but noticing the general sense in which the word "member" was used in the annual reports of the Council and elsewhere throughout the Institution Proceedings, he had

preferred to adhere to the simpler form of the original motion by using the word in that wider sense, so as to include also associates and graduates.

With reference to the building of a house for the Institution, in this matter for his own part he shared the views of a humorist who had once remarked that he did not see what posterity had done for him. There were many like himself he believed, who had moderate salaries under government, and at a certain time would have to retire on a small pension; and in such cases an annual subscription of only a few pounds would then mean a considerable amount. It was altogether a practical question. For those who wished to provide for a house, he could not see that there was any objection at all to their either keeping up their subscriptions if they liked, or else making a present of money to the Institution; but he thought that every member who had paid £90 in annual subscriptions ought thereby to become a member for life.

With regard to the loss consequent upon the passing of the motion, he thought that in subsequent years, as imagined by Mr. Cowper, the loss would be more than the sum which had been estimated as the immediate amount at starting. At present the thirty years' period reached back to the early times when the membership was small and the elections small also; but by and by the increase of membership in former years would begin to make itself felt, and the loss would be more. On the other side there would be a gain by the reduction of the number now retiring annually. Meanwhile it must also be remembered that many more new members would now be joining; so that in this way it was possible there might not be any increase of loss.

Mr. JOHN G. MAIR-RUMLEY, Member of Council, in view of the remarks made by Mr. Wicksteed and Mr. Marshall—and of the wider sense in which Mr. Gray had explained that he intended the word member to be understood in the motion, so as to include also associates and graduates—moved as an amendment that the word member in the motion should not apply to graduates. In his opinion the graduates of the Institution received such great advantages from

(Mr. John G. Mair-Rumley.)

it at a particularly low cost to themselves that he considered the subscriptions they had paid as graduates ought not to be taken into account or deducted from the total of £90 prescribed by the motion.

Mr. BENJAMIN WALKER, Member of Council, seconded the amendment.

Mr. T. HURRY RICHES, Member of Council, was of opinion that the total amount contributed in subscriptions should be the criterion, so as to place every one, whether member or graduate, upon a common footing in regard to the motion. Then those who had entered as graduates and had afterwards become members would have to continue their subscriptions just so much longer than the thirty years as might be necessary to make up the same total amount of £90, which would have to be paid to the funds of the Institution in the form of annual subscriptions before they would become entitled to the benefits of the motion.

Mr. J. F. FLANNERY observed that in the motion, as now proposed in accordance with the wording of the notice given at the previous meeting, the word *member* alone was used; and in regard to the wide meaning assigned to it by the proposer, he enquired what was the meaning it bore in the articles of association.

The PRESIDENT replied that it was provided by article 9 that no graduate or associate should be deemed to be a member within the meaning of the articles; and throughout the by-laws the word member was limited to the same sense, as not including either graduates or associates. It therefore did not seem consistent with the existing by-laws that the word should be understood in a wider sense in the motion now proposed. In order to avoid confusion, he would accordingly suggest the desirability of restricting the motion to the case of members who had paid their full subscription of £3 for thirty years. If the motion were carried in this strict sense, the case of graduates or associates could then be dealt with afterwards by a separate resolution. If the present motion were negatived, there

would be an end of the matter. On the understanding that the word member did not include graduates or associates, there would of course be no need for the amendment which had been proposed.

On this understanding the amendment was withdrawn; and the original motion being then put to the vote was negatived by more than three to one.

The following Paper was then read and partly discussed:—

"On some different forms of Gas Furnaces;" by Mr. BERNARD DAWSON, of Malvern.

Shortly after Ten o'clock the Meeting was adjourned till the following evening. The attendance was 96 Members and 44 Visitors.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, 30th January 1891, at Half-past Seven o'clock p.m.; JOSEPH TOMLINSON, Esq., President, in the chair.

The Discussion upon Mr. Dawson's Paper on some different forms of Gas Furnaces was resumed and completed; and the following Paper was read and discussed:—

"On the Mechanical Treatment of Moulding Sand;" by Mr. WALTER BAGSHAW, of Batley.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated shortly before Ten o'clock. The attendance was 63 Members and 42 Visitors.

ON SOME DIFFERENT KINDS OF GAS FURNACES.

By Mr. BERNARD DAWSON, of Malvern.

Since the two papers read by the late Sir William Siemens before this Institution on Regenerative Furnaces (Proceedings 1857 page 103, and 1862 page 21), several papers upon gas producers and various forms of regenerative gas furnaces have been read and discussed during the last few years at the meetings of other kindred institutions in this country; but as far as the author is aware, they have either been devoted chiefly to the description of particular forms of reversing regenerative furnaces, or else have been reviews of the progress made in the construction of gas producers in various countries. Omitting now any reference to the rival generators or producers in which the heating gas must first be made, the present paper will describe a few typical or representative varieties of Gas Furnaces.

The greater number of gas furnaces in which crude heating gas has been successfully applied have been of the kind now universally known as Reversing Regenerative Furnaces. There are many processes however—requiring various degrees of temperature below that which can be maintained with any regularity by the use of regenerators only (of the kind associated with the name of Sir William Siemens)—in which gas furnaces have been used with some degree of success, both as regards economy in quantity and quality of fuel consumed to do a given quantity of work, and also as regards increased speed of work, saving in wear or destruction of the furnaces themselves, saving in labour, abolition of smoke, and the certainty of being able to maintain an atmosphere or flame either of a reducing or of an oxidising nature: the two latter being essential conditions in many manufacturing processes. In large works it is

often a further great advantage to be able to concentrate in one place the manipulation of all the fuel required in the various furnaces scattered throughout the different departments or shops, as also to avoid the nuisance arising from having to clean the fires and to remove the ashes. It is therefore at times a distinct advantage to employ gas for heating furnaces in which the saving in cost of fuel is itself a secondary or comparatively unimportant matter.

The exact point at which it is advantageous to dispense with the somewhat costly system of reversing regenerative chambers is one on which there is some diversity of opinion. There are of course many furnaces, which can be and are being heated by gas, in which the temperature required is not high enough to render reversing regeneration either economical or even advisable; and the present paper is intended to illustrate a few such cases. It is probable however that the many comparatively low-temperature gas furnaces, to which such regeneration has been successfully applied at the new locomotive works of the Lancashire and Yorkshire Railway at Horwich, may lead to this form of furnace being more generally adopted in future for such work as annealing steel castings, heating plates and angle bars for locomotive and marine boiler work and for shipyards, where a uniform temperature all over a large plate is required for flanging or bending. On the other hand there are many furnaces in which the higher temperature required is such as cannot be attained by the combustion of producer gas with cold air, but in which, with air heated in flues by radiation or conduction from the bed of the furnace and from the flues leading from the furnace to the chimney, a satisfactory result is attained, with some saving in first cost in building the furnace, and without the necessity for much excavation below the bed or hearth of the furnace. The use of gas with cold air is necessarily wasteful, owing to the inability to recover the waste heat from the flame or products of combustion before they pass away to the chimney; and this waste may be prevented by the employment of what may be termed continuous, as opposed to reversing, regeneration.

In furnaces of this kind, as also in those with reversing regeneration, care must be taken to ensure that the escaping gases or waste heat shall

pass into the chimney flues at a sufficiently high temperature to secure the amount of draught requisite for working the furnace advantageously. The author has seen many reversing gas furnaces, in which, in the anxiety to provide area enough in the regenerators to recover the waste heat instead of letting it pass to the chimney unused, the temperature of the escaping gases at the entrance to the chimney has been so low as to make the furnace a failure, either entirely or comparatively. Inattention to the real principles of gas furnaces has done much to bring into disrepute the Siemens regenerative furnace for reheating piles and ingots and for other similar processes; and the author thinks that the recent remarks of Mr. John Head in the discussion upon Sir Lowthian Bell's paper on gaseous fuel at the Paris meeting of the Iron and Steel Institute (Journal 1889 II, page 154) are well worth the attention of those who complain of the inefficiency of many reversing furnaces in this country. Not long ago there was an instance of a reheating gas furnace which was working very badly, and using considerably more fuel per ton of ingots heated than the coal-fired furnace which it had replaced. It certainly appeared to possess every fault which such a furnace could have; and on enquiry it was found that it had been built from the drawings of an open-hearth steel-melting furnace, with no alteration except the provision of a flat hearth, and the substitution of a cinder or slag spout in place of the casting spout of the steel furnace. This is believed by the author to be by no means an isolated instance of the way in which home-made or rather home-designed gas furnaces are sometimes erected. Unfortunately designs for gas furnaces of different kinds, both regenerative and non-regenerative, and with various forms of continuous regeneration, have been proposed to manufacturers and carried out by them in ignorance of the true principles of combustion of gaseous fuel; and the author has known some egregious and costly failures with experimental and untried furnaces for various special processes during the last ten or eleven years that he has been engaged in this class of work. Some of these furnaces, by attention to the bad results attained and study of the causes, have ultimately been made to succeed. Others, either from inability to rectify them or from disinclination of their users

to spend money upon further trials, have been abandoned. An instance of the failure of a reversing regenerative furnace to give any satisfactory result occurred in South Wales some years ago in a long furnace intended for the close-annealing of tin plates; in that case, owing to the length and shape and temperature of the furnace, there was practically no heat left to regenerate when the waste gases quitted the furnace. This same furnace is now working satisfactorily with some slight continuous regeneration or heating of the air used for combustion of the gas. In many cases, where the low level of the land on which the furnaces are built, the presence of water below the ground line, and other local circumstances, preclude the use of underground reversing regenerators, continuous regeneration has been successfully adopted.

Gas furnaces may therefore properly be divided into four classes, namely:—(*a*) with reversing regeneration; (*b*) with continuous regeneration; (*c*) non-regenerative; and (*d*) with blow-pipe or forced blast.

(*a*) *Furnaces with Reversing Regeneration* are of several different kinds:—

1. The ordinary Siemens furnace, in which both gas and air are heated before admission to the interior of the furnace, by being passed through the well-known arrangement of brick chambers filled with chequer work or loosely piled bricks.

2. The Batho or Hilton furnace, in which the regenerative chambers, instead of being partly or entirely underground, are encased in cylindrical wrought-iron vessels erected upon the ground level.

3. Furnaces in which the air only is regenerated by being passed through chambers, the gas being admitted direct from the flues by which it arrives from the producers. In these furnaces the whole of the escaping gases or waste heat has to pass through one of the two air-chambers on its way to the chimney.

4. The furnace recently described by Mr. Head (Iron and Steel Institute Journal, 1889 II, page 256), in which a portion of the waste heat is taken back to the gas producer.

5. The various regenerative blast-furnace stoves of the Cowper, Whitwell, and other kinds. For the purposes of the present paper however these are not considered as gas furnaces, and will therefore not be further referred to.

(*b*) In *Furnaces with Continuous Regeneration* the air, before admission to the interior of the furnace, is heated in flues or pipes, by radiation or conduction from the bottom of the furnace, and through thin walls which separate the air-flues from the flues that carry the spent gases or waste heat to the chimney.

(*c*) In *Non-Regenerative Furnaces* the air is admitted to the interior of the furnace at its natural or atmospheric temperature.

(*d*) *Blow-Pipe or Forced-Blast Furnaces* are of two kinds:— firstly, those in which the air is supplied at its natural or atmospheric temperature by a fan or blower; secondly, those in which the air so supplied is heated by the spent gases or waste heat from the furnace, by being passed either through coils or stacks of pipes or else through brick tubes or flues, as in the case of the Radcliffe furnace and others.

Furnaces with Reversing Regenerators for both air and gas have of course been built principally for such high temperatures as are required for melting steel, copper, nickel, zinc, and glass; for heating iron piles and steel ingots; for forging furnaces, and heating furnaces in connection with stamping and flanging presses; for tire furnaces, tube welding, heating gas-works retorts, burning pottery and bricks, and so forth. Reversing furnaces in which the air only is regenerated are used for annealing steel castings and wire, for burning pottery, for melting brass and phosphor bronze, for annealing nails, and for other such purposes not requiring intense or welding heats.

In Plate 1 is shown a section of a 24 pot or crucible steel furnace.

Figs. 2 and 3, Plate 2, show a 12-ton basic steel furnace of the kind introduced by the late Mr. Batho, in order to obviate the necessity of having the furnace regenerators below the ground line. Many of the earliest furnaces erected of the ordinary Siemens type had the entire weight of the furnace and its charge resting upon the arches of the

regenerators. This is now never done; and in addition to this drawback to the early Siemens furnaces, Mr. Batho called attention to the difficulties connected with underground regenerators, in regard to water and to the time occupied in changing the soap bricks or chequer work; and in these and other respects he claimed important advantages for his plan of encasing the regenerators in wrought-iron vessels above ground.

Fig. 4, Plate 3, shows an ordinary Siemens furnace with the regenerators above ground. This was built in America. The difficulty is not so much that of minimising loss of heat by radiation as of keeping the brickwork gas- and air-tight. It is illustrated as an interesting attempt to solve the difficulty, necessarily arising upon some sites, of providing regenerators above ground.

Figs. 8 and 9, Plate 4, show what is probably the smallest regenerative heating furnace used. Its hearth contains only 12 square feet of area.

Figs. 10 and 11, Plate 5, show a bar-heating furnace for ship-yard and boiler-shop work. The flues beneath it form its reversing regenerators.

Figs. 12 and 13, Plate 6, show a reheating furnace for ingots or piles &c., in connection with a plate mill.

Figs. 14 and 15, Plates 7 and 8, show a 10-ton basic open-hearth furnace.

Figs. 16 and 17, Plate 9, show a furnace for heating tires, with air regeneration only.

Figs. 18 and 19, Plate 10, show an intermittent glass tank-furnace erected for a small glass works in South America, which is shown as being probably the smallest glass tank-furnace ever built.

Figs. 20 and 21, Plate 11, show an open-hearth steel-melting furnace, as designed and erected by Mr. Smith Casson at Earl Dudley's works at Round Oak. The engravings are prepared from the drawings of a 20-ton basic furnace which is about to be erected; the one already at work there is of 6 tons capacity, and the arrangement of the two is almost identical. This shows yet another type of furnace designed to obviate the necessity of going below the ground line for the regenerative chambers &c.; and the inventor

states that no difficulty is experienced in drawing the heated air and gas from these overhead regenerators down to the furnace, and that the results obtained show the loss by radiation to be very small, and that there is no trouble with leaky joints in the brickwork of the regenerator walls. The furnace is heated by gas from two Casson gas producers, and is turning out twelve casts of mild steel per week. Blast—that is to say, air under slight pressure—has been introduced into the box of the butterfly air-valve; but with better chimney draught it is expected to be able to dispense with this.

Continuous-Regeneration Furnaces are used for muffles, low-temperature annealers, furnaces for close and open annealing of sheet iron and tin plates, of brass and copper tubes, cartridge cases, and wire.

Figs. 22 and 23, Plate 12, show a furnace for close-annealing sheets or tin plates, with continuous regeneration. In one portion of it the top of the truck or bogie carrying the pots or boxes of plates forms itself the bottom of the furnace, the joint being made air-tight with sand; in the other portion the boxes are run in and out on cast-iron balls.

Figs. 24 to 29, Plates 12 and 13, show annealing ovens for cartridge cases, thin metal, brass and copper wire, brass shells, &c. Both kinds have a certain degree of continuous regeneration. Some very successful furnaces on this principle have been designed by Mr. Brook of Huddersfield, for heating iron and old steel rails for re-rolling into smaller sections of bars &c.

Non-Regenerative Furnaces are used for such low temperatures as are employed for evaporating brine, for boiling and distilling oil and tar, brewing pale ale, drying slurry in cement works, drying foundry cores and moulds, revivifying charcoal in sugar works, and burning carbon for electric-light purposes. Also for firing steam boilers of all kinds; for heating revolving and other furnaces at chemical works, black-ash and sulphate of soda furnaces; for evaporating waste leys and black liquor in paper mills; for roasting and calcining ores; and for many other industrial purposes too numerous to recapitulate.

Figs. 30 and 31, Plate 14, show a plate-heating furnace in use in locomotive and other boiler shops.

Figs. 32 to 34, Plate 14, show a sand-drying or calcining furnace for an open-hearth steel plant.

Figs. 5 to 7, Plate 3, show gas applied to foundry core and mould stoves.

Figs. 35 and 36, Plate 15, show a gas-fired oil boiler or still.

Figs. 37 and 38, Plate 16, show a gas-fired slurry floor in a cement works.

Figs. 39 and 40, Plate 16, show a gas-fired brewer's copper.

Figs. 41 to 44, Plate 17, show a Lancashire and a Babcock and Wilcox boiler, both of them fired by gas.

Blow-Pipe Furnaces, into which heated air required for combustion is delivered under pressure, have been used for puddling iron, melting brass in pots, heating plates for stamping into railway sleepers, melting zinc ores, welding tubes, &c. But with the exception of some few puddling furnaces on the Continent, the author believes that this application of producer gas has not yet been carried to a success; the difficulty in working any such furnaces as he has had an opportunity of seeing has consisted in maintaining a regular flame or heat, because the slightest variation in the volume, pressure, or quality of the gas produces immediately a marked effect in the furnace. It is also essential that the annular orifice through which the air is forced in, all round the gas inlet, should be of perfect workmanship and smooth surface, and of correct shape and proportion; this condition, with fire-clay or fire-brick nozzles exposed to the fierce heat of the gas blow-pipe, is very difficult to preserve; while the attempt to provide for the continual variation in the gas, by using a sliding or adjustable cap or nozzle to the blast pipe, has proved impracticable. Some of these furnaces have worked admirably in an intermittent way; and the conclusion apparently arrived at has been that they are too delicate and complicated to be handled by ordinary furnace-men.

Fig. 45, Plate 18, shows a revolving furnace worked with gas and heated air, the latter being supplied through a blow-pipe nozzle.

Figs. 46 and 47, Plate 19, show a furnace worked successfully for heating thin plates for stamping into railway sleepers &c.

Figs. 48 and 49, Plate 20, show a crucible silver-melting furnace with blow-pipe.

Figs. 50 and 51, Plate 21, show a Radcliffe steel-melting furnace.

The failure of some *non-regenerative* furnaces may be attributed to losing sight of the different specific gravities of hot producer-gas and cold air; and also to neglecting to impart to the air, before it meets and mixes with the gas, some impetus or motion in the same direction in which the gas is travelling on its entrance into the furnace. For instance, where cold air is admitted in a horizontal stream over the gas which is rising vertically or obliquely from the gas valve, intimate mixture and perfect combustion are rarely attained; in addition to which, small explosions and other troubles are frequently experienced. In other cases the introduction of the gas and cold air into the furnace in parallel streams, or in any large volumes, either side by side or over one another, has led to failure. In furnaces to be heated by gas and cold air, either the volume of each should be split up into a number of small streams by perforations in the walls forming the inlet to the furnace; or else some form of combustion chamber should be provided, in which the gas and air can be mixed and partially ignited before admission into the actual furnace itself. The regulation of the pull or draught of the chimney on the furnace—so as to draw in just sufficient cold air for burning the gas, without drawing unburnt gas into the chimney—although often neglected by the furnace-men, can easily be effected with a little care, provided that the respective sectional areas of the gas and air inlets and of the outlet to the chimney have been duly considered in the building of the furnace.

There are many boilers, both Lancashire and Cornish, with provision for heating the air before its admission to the boiler furnaces; and at the works of Messrs. Nettlefolds at Tydu near Newport, Monmouthshire, this is said to have proved to be well worth the trifling extra expense and complication in the boiler seating and flues.

The failures of many small applications of gas with cold air to such furnaces as annealers for glass bottles, foundry stoves, annealers for light castings &c., has no doubt been often due to the neglect to keep the doors of such furnaces tightly closed; the result has been lack of chimney draught to draw air in *at the right place* for combustion with the gas. Many such furnaces properly attended to are giving entire satisfaction in regular work.

It scarcely comes within the scope of this paper to review all those that may be called semi-gas furnaces, in which the combustion or at least the ignition of the gas takes place partly in the grate or producer as well as in the furnace itself. The names of many such furnaces are too well known to need mention here, and most of them have been fully described elsewhere; and as they come under the head of gas producers quite as much as under that of gas furnaces, they are omitted from the present paper.

Reversing Regenerators. — The principles and construction of furnaces with reversing regenerators for both gas and air are now much better and more generally understood than was the case only a few years ago. It is curious however to what a small extent gas crucible furnaces have been substituted for the old furnaces or "coke holes" in which the greater part of the crucible steel melted in Sheffield is still made. When it is considered that, according to the size of furnace and other details, a ton of crucible steel may be made with from 33 to 40 cwts. of small coal in a gas furnace, against from 52 to 60 cwts. of coke in a "coke hole," it might be thought that more success would have attended the efforts on the part of the Sheffield steel makers to overcome the trade prejudices existing against such innovations as melting steel in crucibles with gas. The many objections heard from time to time, as to inability to keep a mellow heat or to regulate the heat and the draught, are such as can certainly be overcome; there may however be other objections and difficulties, with which only those actually engaged in steel melting are acquainted. The objection most frequently urged against the use of gas for furnaces melting steel of special tool qualities is the inability to control each pot or pair of pots in a large furnace. It

is of course necessary to have a furnace which will hold a number of pots, in order that the cost of regenerators &c. may be distributed over a larger output of steel than would be the case if a complete gas furnace had to be built for each pair of pots; but there appear to be no insurmountable difficulties in the way of regulating the heat of each pot in a furnace containing say twelve or twenty-four crucibles.

With so many different means of attaining and regulating the temperature in gas furnaces, and with such perfect control over the admission of gas and air and over the chimney draught, there are few industrial processes requiring heat to which producer gas ought not to be capable of being advantageously applied. The question of extra first cost in the erection of new furnaces, and the impossibility of applying gas to existing coal-fired furnaces with any degree of success, have very much prevented the extension of gas firing: although the erroneous ideas prevalent as to the necessarily complicated nature of gas furnaces, and as to the cost in repairs and maintenance, have probably done quite as much to prevent many such furnaces from being built.

Reversing Valves.—The best arrangement of valves for reversing regenerative furnaces is a matter of some importance; for with leaky valves the waste of gas directly up the chimney from the main gas-flue is very great. For gas the use of the ordinary "butterfly" reversing valve is being superseded by that of "pot" or double-beat mushroom or pan valves, as being less likely to become warped through carelessness or neglect. For air the butterfly valve is generally used. For small and medium sizes of heating furnaces, butterfly valves, if made sufficiently large, work well enough. A gas-valve too small for its work soon becomes overheated, warped, and leaky. The tendency in most regenerative furnaces for the greater part of the spent gases or waste heat to pass down through the gas-chamber to the chimney, in preference to passing down through the air-chamber, is one which leads to the trouble with the gas-reversing valve. This can be averted however by two or three means: by the chequer work being less closely stacked in the air-chamber; by attention to the

shape and position of the passages and ports between the furnace and the air-chamber; and by the provision of dampers. In addition to the valves above mentioned, there are also the hydraulic slide-valves of Mr. Le Neve Foster; water-seated valves; and the revolving valves designed by Mr. John Ramsbottom, which, if carefully made and seated, are probably as simple and efficacious as any in use.

With regard to ingot and other reheating furnaces, an objection is raised that, whereas with a coal-fired furnace the furnace-men attend to the fire themselves, with a gas-fired furnace they would not or could not attend also to the gas producer, which thus entails an extra man: or say three extra men for a group of producers supplying gas to a number of reheating or mill furnaces. This question of extra labour has not unnaturally been brought forward in connection with various combinations of gas producers and furnaces, as showing the advantage of having the producer attached to its own furnace. The disadvantages of this plan appear to be that, whenever from any reason a furnace is stopped, the gas producer connected with it must stand too: representing so much idle capital, and therefore a greater total expenditure in gas producers than where say a dozen producers are erected all together to supply a number of furnaces of which only a certain proportion are ever at work at the same time. The necessity of having to convey fuel and ashes to and from several furnaces in large works is also a disadvantage in the plan of combined producer and furnace. The loss of heat by radiation, in the passage of the gas from the producers to the furnaces, is sometimes adduced as an argument in favour of the combined plan; but with properly constructed flues this is more imaginary than real. Even where there is any appreciable loss of heat, it is more often than not an advantage in saving wear and distortion of the valves; and, as has been often pointed out, there is frequently an absolute economy in fuel by using cooled gas: besides which there are minor advantages, such as that the dust contained in gas made from some coals is deposited in the flues instead of in the furnaces themselves. Most of the combined furnaces depend for their economical working

upon a steam boiler of some kind, to utilize the waste heat or gases which would otherwise pass unused to the chimney.

The new form of gas producer lately described by Messrs. Head and Pouff (Iron and Steel Institute Journal, 1889 II, page 256) does not possess this disadvantage, as there are regenerators into which a portion of the waste heat is conducted, another portion being introduced under the grate bars of the gas producer. So far as can be judged from its principle, and from the figures and analyses given, the chemical reactions in this furnace appear to be theoretically correct. Time alone will show what is its cost of maintenance, and its capacity for continuous work; and also whether the economy which is stated to have been attained is not due to the superiority of the general arrangement of the furnace itself rather than to any great benefit derived from the attempt to take carbonic acid from the furnace and introduce it beneath the grate bars of the producer. Some users of this new furnace are said to be doubtful as to the good they have thus derived; and the plan of taking heated air direct from the regenerators and using it under the grate bars of the producer has recently been devised by Mr. Frederick Siemens. In any case the employment of the nitrogen of the air as a vehicle for conveying heat from the spent furnace-gases into the furnace again by the medium of the producer is an ingenious plan; and a considerable number of furnaces on this principle have been built.

The Gorman heat-restoring gas furnace is another of these combined furnaces and producers; but in this a continuous regeneration is effected by passing air through a number of fire-clay tubes. These furnaces the author understands have been erected at the Clydesdale Iron Works, Glasgow, and at several ship-yards in England and on the Continent.

The Radcliffe furnace, Plate 21, which is in use for melting steel in the gun factory at Woolwich Arsenal, is another instance of the combined furnace and producer; and Mr. Radcliffe states that by its use he has succeeded in effecting considerable saving in fuel over Price's retort furnaces, which this plan has superseded. In this furnace steels of various degrees of hardness are produced, and the author is assured that it is giving complete satisfaction in all

respects. In this furnace also air is heated by transmission through fire-clay tubes.

The Boetius furnace, which is used in a few of the glass works in this country, may also be classed with combined furnaces. There are several varieties of this furnace; but such of them as the author has been fortunate enough to see are fed with coke all round an annular space, from which the fuel slips down into an arrangement of grates with bars, over which are arches whereon the pots containing the glass are arranged. There is no reversing regeneration. A description of this, as well as of similar furnaces for zinc melting, and also of several forms of gas retorts, and of porcelain-burning, lime-burning, and other furnaces, was given by Mr. Ramdohr in pamphlets published in Leipzig in 1881.

A furnace which is claimed to be superior to the Boetius for melting glass in every sort of pot furnace has been introduced recently by M. Regnault, and uses small coal instead of coke; and M. Regnault states that he has erected a considerable number on the continent. This also is a combined gas producer and furnace, with the grate below both the floor and the sieges upon which the pots stand.

Glass Furnaces.—Reversing regenerative furnaces are now largely used for melting glass, and there are several forms of glass furnaces.

1. Continuous tank furnaces, in which the process of melting the raw material goes on at the same time that the melted glass is being blown into bottles or into cylinders for sheet glass. In most of these furnaces, the sand, soda, &c., are fed into one end, while the gatherers or blowers are arranged round the other end.

2. Intermittent tank furnaces, in most of which the material is melted by night and blown during the day.

3. Pot or crucible furnaces.

These three processes of glass making are much akin to two of the steel melting processes carried on in what are known as open-hearth and pot or crucible furnaces.

In glass works, gas is also used for annealing bottle and plate glass; for the "glory holes," in which in some works the necks of the bottles are finished; and for other small accessory furnaces.

In tube works, furnaces with reversing regeneration are used for welding iron tubes for water and gas and steam, although the use of gas furnaces has not at present extended beyond a few of the largest works.

In the manufacture of steel, the principle and uses of the open-hearth furnace are well understood. Of this furnace, as suited for the acid or hematite process, some modification has been found by experience to be advisable for working on the basic process. Acid furnaces are at work in this country, varying from 2 tons up to 40 tons capacity. The wisdom of building furnaces of over 20 or 25 tons capacity has been questioned. It is usually possible to obtain a greater number of casts of steel per week from the smaller furnaces; and where the total capacity in a works is divided among several smaller furnaces, instead of being concentrated in one or two very large ones, times of repairs involve less capital standing idle, fewer highly paid men thrown out of work, and less interruption in the supply of ingots to the mills. Into the vexed question of the relative consumption of fuel in large and small furnaces, it is not here intended to enter. Were there many works in which both large and small furnaces were employed, using gas from the same fuel and using exactly the same raw materials, the subject might prove profitable for discussion. The same is true of the conflicting testimony in favour both of coal-fired and of gas-fired furnaces of all sorts. Be it borne in mind however that there are both good and bad furnaces, and both good and bad furnace-men. There is also some diversity of opinion as to the propriety of using the open-hearth furnace for making the higher class of tool-steel and other special steels; it is this probably that has helped to check the extension of regenerative crucible or pot melting-furnaces in place of the coke holes already alluded to. Whenever water-gas, made by the processes recently introduced, becomes adopted for melting steel in the open-hearth furnace, it will probably be used in furnaces provided with means for air regeneration only.

Open-hearth furnaces and regenerative crucible furnaces for melting brass and phosphor bronze &c. have not been used to any great extent in this country or abroad, as far as the author is aware.

Many objections are raised by brassfounders to the use of gas furnaces for melting any forms of brass or metal which contain zinc or spelter. These however do not appear to be insurmountable, as there are some gas furnaces so used at the Horwich locomotive works of the Lancashire and Yorkshire Railway, which give no trouble in this respect.

Water-Gas Furnaces.—The application of jets of water-gas to welding large tubes, boiler flues, seams of sugar pans &c., at the Leeds Forge, and at Messrs. T. Piggott and Sons, Birmingham, and Messrs. John Brown and Co.'s works, Sheffield, can scarcely be accurately regarded as constituting distinctive furnaces, and therefore admit of no more than passing mention. But Mr. Oakman, the European representative of Mr. Loomis (Proceedings July 1890, page 402), has recently applied water-gas, made by this process from small coal, to a crucible-steel furnace, to a furnace for baking clay crucibles, to an annealing furnace for tubes, and to another for tube welding at Messrs. Howell's works in Sheffield; and other similar furnaces at work in the United States upon this system have been illustrated and described in the technical papers. Arrangements are made by which these furnaces can be supplied either entirely with the producer or "by" gas from the water-gas plant, or with a mixture of this by-gas and water-gas, the proportions of each being regulated by valves at will. It is to be hoped that before long some information will be furnished as to comparative cost of fuel and labour, and also as to the time saved and the increased output attained by the use of mixed gases: so that the expediency of erecting water-gas plant, in order to make and store two gases separately, and then mix them again before use, may be definitely settled. It is beyond doubt that there are many purposes—such as tube welding, heating bolt and rivet iron, chain welding, and other processes requiring a high local temperature concentrated upon a small surface or upon a small portion only of a large surface—to which ordinary producer-gas has never been advantageously applied, and for which pure water-gas appears to be very suitable. The Loomis water-gas plant erected by Messrs.

Howell is stated by them to be working to their entire satisfaction and with economy and regularity. Some of these furnaces have continuous regeneration, and others reversing, of the air alone in every case. Similar furnaces are now being erected for making wrought-iron wheels, and for melting steel and glass, to be worked by water-gas made from coke, on the same principle that is in use, as above mentioned, at the Leeds Forge.

The Ponsard revolving steel furnace, having continuous regeneration of air by means of a chamber filled with hollow bricks, is another form of furnace with producer attached.

Among other applications of producer gas upon the reversing or continuous regenerative principle are those devised some years ago by Mr. Dunnachie, and used in the production of the Glenboig brand of silica bricks, and at Bournemouth for burning glazed sanitary pipes, and in a modified form for Staffordshire blue bricks at Tamworth, and for pottery in North Staffordshire. In this case the gas producers do not form an integral part of the furnaces or kilns, but stand at any convenient distance away. In these kilns the products of combustion from one kiln are drawn by chimney draught through the next kiln in the series, and the "green" bricks are dried by this waste heat on its way to the chimney. The kiln which is being fired, that is, in which the gas is being burnt, is supplied with hot air drawn from the kiln last fired, the air thus heated having been used to cool the bricks in that kiln. A continuous cycle or series is thus maintained. The author believes that Mr. Lowood has for some years been working kilns upon this principle in the neighbourhood of Sheffield. Messrs. Siemens and others have also devised arrangements of regenerative gas kilns for brick and pottery burning.

The various arrangements of stoves and gas furnaces proposed by Mr. Bull for the manufacture of iron and steel direct from the ore, while highly ingenious, are at the same time complicated and intricate. Both at Seraing and at the experimental works at Trimsaran in South Wales, it is claimed that the expectations of the inventor have been realised.

Retorts for making illuminating or town gas in gas works have been heated by producer gas made both from small coal and from the coke raked out from the retorts themselves, and have been arranged both with continuous regeneration and reversing regeneration of the air, but have never been extensively adopted. Descriptions of such furnaces have been given by Mr. Foulis of Glasgow, Mr. Charles Hunt of Birmingham, Mr. Denny Lane of Cork, and others; and the Klönne and other systems of combined furnaces and gas producers have been introduced in many large gas works with success. But to describe them here fully would take too much time and space; and as their design and construction are familiar to all interested in making town gas, and are probably of no general interest beyond, further reference to them is omitted.

The mention of Mr. Fletcher of Warrington calls to mind a large number of gas furnaces, principally on a small scale, and applicable to a great variety of purposes. As far as the author knows they have been confined to the use of ordinary illuminating or town gas. There are few industries requiring the intelligent use of purified gas which are not indebted to the patient investigations and experiments of Mr. Fletcher. It is however somewhat outside the range, even of a discursive paper like the present, to examine or illustrate these manifold applications to the minor industries of this country. Mr. Emerson Dowson's various applications of heating gas deserve recognition; and it is to be hoped that at some future date the various types of small gas furnaces, to which these truly belong, will be treated of.

In the face of the discrepancies in the statements of the highest authorities in the iron and steel and other allied industries, as to the comparative waste of iron and steel in gas furnaces as compared with coal-fired heating furnaces, the author will merely suggest that careful examination might very possibly lead to the detection of the cause of any waste on ingots reheated by gas, say exceeding 4 per cent. waste, such as has been complained of by some users of these furnaces. The possibility of preventing by the use of gas oxidization or scale in tube-welding, annealing, and other similar furnaces, may

be taken to be fully established; and in the copper, brass, and other metal trades there is some evidence to show that discoloration of metal, such as brass wire, cartridge cases, &c., may be prevented even in furnaces which are open or only partially closed. Thus the heavy consumption of fuel for heating coal-fired muffles, or furnaces that are entirely heated internally by radiation or conduction through thin walls, may be considerably reduced. In some cases where experimental or trial furnaces have been built and supplied by gas from a single producer, their failure and abandonment have been caused by the varying or intermittent supply of gas. There are however producers of different forms which may be relied upon to supply gas of a uniform quantity and quality from a single producer. It is possible that undue stress has been laid upon the loss of heat when coal is used in a gaseous form, owing to radiation from the producer in which it is gasified. No doubt this does take place; but with well-designed furnaces this initial loss should be more than compensated for, by the control over the supply of air admitted for combustion, by regeneration, and by the more perfect combustion of the fuel itself. Mr. Holley, in his presidential address to the American Institute of Mining Engineers, said that "regenerative furnaces will gradually, but inevitably, take the place of the ordinary heating, puddling, and melting furnaces, thus preventing the application of unspent furnace heat to steam generation." That was in 1875, and yet how much still remains to be done.

In the chemical industries such a variety of gas furnaces have been introduced that, without doing more than mentioning Mr. MacTear's carbonating furnace, the Jones and Walsh salt-cake furnace, and the sodium and aluminium furnaces designed by Mr. Cullen for the Castner-process aluminium works at Oldbury, the author must content himself with expressing his belief that before many years have passed the rising price of fuel will have increased the number of chemical and alkali and other works in which the use of gaseous fuel will have superseded the employment of solid smoke-making coal. Whether Sheffield will by this means become in our day as clean and clear in its centre as it is beautiful in its suburban

surroundings is beyond any present means of calculation. The old workmen, who can never be led to believe that there can be any useful heat without much visible smoke, are being replaced by younger men, wanting or inferior perhaps in many of their predecessors' best characteristics, but more and more convinced of the necessity for employing the cheaper forms of fuel available in the furnaces reviewed in the present paper.

In conclusion the author asks for indulgence from the many inventors, engineers, and other pioneers in the use of gaseous fuel, whose valuable and original discoveries in this process of manufacturing industry he has omitted to notice, either from ignorance or through inadvertence, or from the necessity of keeping this paper within reasonable limits. No attempt has been made to examine the chemical actions or reactions in the various furnaces described; nor to treat in any way of the thermic value of fuel used in a gas furnace as opposed to one fired by hand with solid coal.

Discussion.

Mr. JOHN A. F. ASPINALL, referring to the mention made in the paper (page 48) of certain furnaces which he had shown the author a year or two ago at the Horwich works of the Lancashire and Yorkshire Railway, said that at that time there were three gas furnaces which were worked with continuous regeneration, that plan having then been tried rather with the view to see if the regenerative chambers could be got rid of. Subsequently however he had altered two of the three furnaces by putting in regenerative chambers. For he had found that, while the third furnace, which was used for the special purpose of annealing steel castings, did well with continuous regeneration, yet in other cases he could not rely upon getting the continuous flow of gas that was necessary to keep the heat up to the proper temperature.

The regenerative chamber, when it was once got to work, formed as it were a kind of accumulator, from which heat could be drawn if the gas did not continue to flow from the producers steadily and regularly.

With regard to the use of gas furnaces for brass melting (page 62), there was one ordinary open-hearth regenerative furnace at the Horwich works, in which was melted all the brass for large castings, such as brasses for axle-boxes. There was in addition a series of regenerative pot furnaces, which were used for the crucibles for melting brass or bronze in the ordinary way. With these there was no difficulty; there had been a little prejudice against them at first, but that seemed to have died away. They were worked in the ordinary manner; and he believed the castings produced from them were quite as good as could be produced by any other method.

With regard to the firing of Lancashire boilers by means of gas (page 54), he knew of one instance where that plan had been successful, whilst in another it had been unsuccessful. The conditions under which the use of gas for firing boilers could be made to be successful were peculiar. It could not be hoped to get boilers to do well with gas firing, unless they were easily driven; if they were hard driven, it was far better to fire them with coal.

The double-beat valve was favourably mentioned in page 57, and he was inclined to agree with the author's opinion of it. Though he had not used it himself, he thought it looked a good mechanical job when it was in its place. He had used exclusively the ordinary old-fashioned revolving Ramsbottom valve, Figs. 60 to 63, Plate 24, for the reason that it could so easily be got at. The many failures which had elsewhere occurred with it he attributed to the fact that as a rule the casing was made too slender to stand the heat. It ought to be much thicker, say from 3 to 3½ inches thick, and then it would not warp or twist in any way. How well these valves would answer when they were properly made was shown by the fact that some of them which were situated at the back of melting furnaces, had now been at work for three or four years, and so far as the casing was concerned they were apparently as good as the day they were put in. The valve itself was of course subject to renewal; and

(Mr. John A. F. Aspinall.)

it was easily and cheaply renewed, owing to the cylindrical form of the casing.

There seemed to be little trouble in getting gas to flow through considerable distances to furnaces in which it was required to be used for such a purpose as spring making and work of that class, where the temperature was not exceedingly high. At one time he had had considerable doubt as to the possibility of getting furnaces to work so far away from the gas producer as he had found could be done. To any members who might be interested in seeing any of the gas furnaces at Horwich he should be glad to show them at any time.

Mr. BENJAMIN A. DOBSON, Member of Council, concurred with Mr. Aspinall (page 67) in regard to firing boilers by gas. He had seen about a score of instances where that had been tried, some abroad and some in this country; and it had invariably been the case that, if the boiler was worked up to anything like what was considered generally the proper rate when firing in the ordinary way with coal, it had been pulled to pieces by the excessive action of the gas flame. Where the boilers were underworked, they seemed to work economically and satisfactorily with gas firing.

Mr. JOHN HEAD considered the members were much indebted to the author for the pains he had taken and the energy he had shown in bringing before them such numerous examples of gas furnaces. Regenerative furnaces were generally known as Siemens furnaces, being due to the genius of the late Sir William Siemens (whose assistant he had himself been for twenty-five years) and of Mr. Frederick Siemens; and the varied purposes to which these furnaces could be applied were illustrated in the present paper. Although this Institution had not had the benefit of any subsequent paper on regenerative furnaces from the late Sir William Siemens since that read in 1862, the literature of the subject was well represented in the proceedings of kindred societies, in whose volumes some of the examples given in the present paper had appeared. Among the illustrations shown, some were given as examples not to be followed, but rather to be avoided; and some were now obsolete.

With regard to the regenerators, he considered that, in all cases in which the gas-producer was placed at some distance from the furnace, four regenerators should be used. The use of two regenerators only was not correct in principle, and had never been adopted largely; nor was that arrangement capable of giving satisfactory results, for the reason that it was impossible thereby to utilize entirely the waste heat of furnaces. If it was tried to do away with the cooling tube for gases on their way to the furnace, a mistake was made; for, inasmuch as a certain weight of hot gases went out of the furnace through the two outlet regenerators in a given time, the inflowing gas and air which supplied the furnace must be capable of taking up the same amount of heat that had been deposited by the outgoing gases; therefore the same weight of cool gas and air must be passed through the gas and air regenerators on their way to the furnace, in order to take up that heat. If this were not done, the consequence would be that the reversing valves would be overheated and damaged, leading to leakage of gas and possibly to its partial combustion before reaching the furnace; and there were other inconveniences which he had known to be produced, in addition to the actual loss of fuel thus caused. In a 20-ton steel-melting furnace the weight of the outgoing gases would be about one ton in five minutes; and from this circumstance it would be easy to estimate the importance of utilizing all the waste heat. In page 48 of the paper it was said to be "at times a distinct advantage to employ gas for heating furnaces in which the saving in cost of fuel is itself a secondary or comparatively unimportant matter." Such cases he thought did not occur often; at any rate in his own experience of thirty years he had never met with them; nor had he ever found any one willing to sacrifice fuel for the sake of obtaining other advantages, such as uniformity of heat or absence of smoke.

The delivery of waste gases into the chimney at a high temperature (pages 48–9), in order to create a sufficient draught, he deprecated. In order to get a sufficient draught for working a furnace advantageously, a chimney high enough for the purpose should be provided; a low chimney heated to a high temperature would mean waste of fuel.

(Mr. John Head.)

The blow-pipe or forced-blast furnaces (page 51), in which the regenerators were made of fire-brick tubes or their equivalents, had been tried many years ago, and found wanting, mainly from the circumstance that the tubes could never be kept tight: there was always a leakage; and of course in such furnaces, if there was a leakage into the chimney at any part of the tubes, the gas or air which was intended to be burnt in the furnace never reached it, and the working of the furnace must suffer in consequence, and loss of fuel would occur. Such furnaces he believed had recently been brought forwards again in the shape of the Radcliffe furnace, shown in Plate 21; but he thought this furnace had not yet received many applications outside the works where it originated. As to the advantage supposed to accrue from building the regenerators in boxes placed at the top or at the sides of the furnace, he did not concur in it. If it was desirable, as in many cases it was deemed to be, to build the heating chamber of the furnace on girders, there was no necessity for having recourse to such expedients. When regenerative furnaces were first introduced, the question of expense had been an important consideration. Some firms after deciding to adopt them had tried to reduce the expense of their application; and if under such circumstances it had been suggested by Sir William Siemens to build the heating chamber upon iron girders, making the regenerators a separate structure, many would have refused to build the furnace, owing to the expense involved. Now that there was more enlightenment upon the subject and more willingness to incur the necessary expense, it was found that there was less difficulty in this respect. But the idea of regenerators on the top of the furnace was not philosophically correct; it was wrong in principle. Heat as it was deposited in the regenerators naturally tended to rise to the top; hence regenerators should be vertical, so that the top of each should be the hottest part, and the inflowing currents should enter at the bottom, so as to become gradually heated as they rose to the top on their way to the heating chamber. In this respect the regenerators introduced by Sir William Siemens were certainly correct; whereas when the regenerator was put at the top the conditions were inverted, and the result was inferior to what it

would be with the regenerator beneath the furnace. No information was given in the paper with regard to the consumption of fuel or the work done with the regenerator on the top of the furnace. That was really the test whether one furnace was better than another; and another test was the wear and tear of the furnace, and on this head also no information had been given in the paper.

The new form of Siemens furnace, referred to in page 50 of the paper, fulfilled all the conditions of a regenerative gas furnace with four regenerators, although it had only two. The gas producer absorbed the heat which otherwise would be deposited in the gas regenerator. By this plan two important advantages were realised: the first was a saving of about half in the cost of construction; and the second was a saving of half in the consumption of fuel. From the diagram of the ordinary gas producer, Fig. 52, Plate 22, it would be understood that air coming in at the bottom would there be converted into carbonic acid, which passing up hot through the superincumbent layer of red-hot carbon would then be converted into carbonic oxide. The principle of the new furnace, alluded to in page 59, was that by introducing carbonic acid into the bottom of the producer half the weight of the carbon in the fuel might be saved, this saving being equivalent to one-third when coal was used. Moreover by putting the producer itself near the furnace, the producer gas could be delivered hot direct into the furnace, with a further economy of fuel amounting also to about one-third; and in this way an ultimate saving in fuel was realised of nearly two-thirds the fuel required to do a certain amount of work in the ordinary regenerative gas furnace. The relation between the original and the new form of furnace was shown by the diagrams, Figs. 53 and 54, Plate 22, in which the course taken by the currents flowing in and out of the two furnaces was indicated by the arrows. In Figs. 55 to 59, Plates 22 and 23, was shown the construction adopted for the new furnace in practical work. The number of these furnaces now built or in course of construction was between fifty and sixty. One of them had a bed measuring 30 feet by 8 feet, and had heated as much as 70 tons of steel blooms per shift of twelve hours. The consumption of fuel measured during three shifts or thirty-six hours

(Mr. John Head.)

of continuous work was only one cwt. per ton of steel heated, in comparison with the other heating furnaces working in the same shop, which consumed four cwts. of fuel to do the same work. A furnace on this plan had been constructed for the manufacture of steel on the open hearth; it was a small furnace, because he wished to commence in a small way, and then go on to larger furnaces; compared with another open-hearth regenerative gas steel-melting furnace working in the same shop, it showed a saving of 50 per cent. of fuel. The use of the regenerative furnace had been strongly advocated by the late Mr. Holley; but the cost of the original form was sometimes found to be an objection to its introduction. The new furnace seemed well suited to fulfil his prediction quoted in page 65 of the paper, as it effected a saving of 50 per cent. in cost of construction, and also a saving of 50 per cent. in working, over the original form of the regenerative furnace.

Mr. R. SMITH CASSON said the open-hearth steel-melting furnace at the Earl of Dudley's iron works at Round Oak, to which attention had been drawn in page 52, was working with only one gas producer, and not two as stated; it was giving great satisfaction, although he would not go so far as to say that he should prefer overhead regenerators to underground ones. In the present case the overhead regenerators, as shown in Plate 11, had been attempted as a matter of convenience more than anything else. There was not the space for putting the regenerators alongside, and they could not be put underground owing to trouble with water; and if the overhead arrangement had not been adopted, the furnace would not have been started at all. The success already achieved with this furnace he was sure would convince any one who saw it at work that overhead regenerators were not to be objected to. Originally the furnace was one commonly known as the Casson-Bicheroux gas heating-furnace, that is, a mill heating-furnace. He was anxious to get Lord Dudley to go into steel making, because he felt convinced that the future of South Staffordshire lay eventually in steel, and especially in steel made on the basic process. He had therefore determined at his own risk to alter the furnace, which at the time

had been lying idle, into a steel one, and to do so by adding to it overhead regenerators; the idea of that arrangement had occurred to himself and to Mr. Talbot, who had assisted him in carrying it out. That small furnace, which in the ordinary course would heat 2 tons of iron or steel per heat, was now producing as much as 80 tons of ingot-steel per week; allowing for stoppages and repairs, the make came to something like 65 tons per week, or about 3,000 tons per annum. There was no difficulty with the regenerators, except that occasionally they sooted up, as all basic-steel regenerators did, which he attributed to the influence of the lime; in all other respects the furnace worked admirably. He considered that it did not do a fair week's work if it did not turn out twelve casts per week, and it had reached as much as fourteen. A cast had been got out in as little as six hours from the time the material was put in. The furnace had worked with 11 cwts. of screened slack per ton of steel cast. The steel made was found to be of excellent quality; in fact it compared favourably with charcoal iron. If it were required to erect a large plant, he did not say that he should go upon the same system of overhead regenerators; but in cases where water in the foundations was difficult to overcome, and where space also was of value, he should certainly recommend placing the regenerators overhead. As regarded continuous regenerative furnaces, heating furnaces of this kind had been at work at Round Oak for thirteen or fourteen years, and had given no trouble. These gas furnaces were turning out 2 tons of iron or steel ingots per heat, consuming $4\frac{1}{2}$ cwts. of slack to the ton of ingots. No doubt with a larger furnace, such as had been mentioned by Mr. Head, 2 cwts. or perhaps only 1 cwt. per ton would suffice; and as there were boilers overhead he considered great advantages and economy in fuel &c. were gained from the steam raised.

Mr. JOHN HEAD thought that melting steel with 11 cwts. of slack per ton, as stated to have been done at Round Oak, did not show a favourable result; and he asked whether the steel was made from pig-iron decarbonized by iron-ore, or from pig-iron simply alloyed with wrought-iron, and whether the pig-iron was charged hot or

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cold into the furnace. There was a great difference between manufacturing steel from pig-iron entirely, and from pig-iron mixed with a considerable proportion of scrap.

Mr. R. SMITH CASSON replied that the proportions used were about 60 per cent. of pig-iron and 40 per cent. of scrap. The pig-iron, which was charged cold, contained from $2\frac{1}{2}$ to 3 per cent. of phosphorus; no doubt if a purer pig were used, the heats could be got out of the furnace much quicker. The steel-melting furnace now turning out 6 tons per cast had simply been converted from one of the ordinary gas heating-furnaces, which had been built originally to heat 2 tons of iron or steel at a time. Considering that this furnace was only a six-ton furnace and that it was being worked with a pig which was so high in phosphorus, practical steel-makers would agree that the consumption of coal was much lower than was usually the case.

Mr. ALFRED SLATER said within only the last two or three months one of the new Siemens regenerative gas furnaces had been erected for heating iron at the Gloucester Wagon Works. Unfortunately owing to their own mistake in using wrong bricks in its construction the furnace went out of repair early: so that he had not been able to get any figures as to the consumption of coal in proportion to the work done, which was of course the crucial test. At the same time he had no hesitation in saying that the furnace had already been found to be a great improvement in regard to economy of coal and economy of repairs, as compared with the ordinary reverberatory furnaces previously used. Since the right bricks had now been substituted, the furnace had given no further trouble in repairs, and had worked well. The consumption of coal he thought would probably be something like one-tenth of what it used to be in the old furnaces. A great deal depended upon the quality of the coal that was used, as was evident from the figures given in Messrs. Head and Pouff's paper (Iron and Steel Institute Journal, 1889 II, page 263), which showed that for doing the same work about 20 per cent. more was required of London screenings than of Newcastle

cobbles. At Gloucester he had been using Forest of Dean coal of the cheaper kind; and he quite expected it would there be necessary to use a larger proportion of coal from the Forest of Dean than from elsewhere. With this coal the furnace had worked well up to a recent Saturday night; but on the following Monday and Tuesday, although the use of the same coal was continued, the iron could not be got hot enough to take it under the hammer. On Tuesday night the coal was changed for another coal from the Forest of Dean, which unfortunately cost 30 per cent. more per ton; but if anything better results were obtained with this dearer coal than with the cheaper. Why it should have proved beneficial to change the coal he did not know. The same men were working the furnace, and it was apparently in exactly the same condition, so far as could be seen externally; but owing to the heat it was impossible to get inside. Whether the difference had anything to do with the state of the atmosphere, or whether any part of the furnace had enlarged owing to the extreme heat, or whether any part of the regenerative chamber below had got out of position, was a question which could only be decided when the furnace was cooled down so that a man could get inside it. This appeared to him to be an important matter for those who had to use the furnace, because, unless they had their own colliery, they would not like to be bound down to use a particular coal, if there was any risk of its being afterwards found occasionally not to answer the purpose. The regenerative heating furnace had been adopted at Gloucester after a good deal of investigation; and notwithstanding the difficulties which had been experienced, he was glad to say he was fairly satisfied with the results up to the present time.

Mr. R. N. OAKMAN, referring to the allusion made in page 62 to his own paper read at the Sheffield Meeting of the Institution last summer (Proceedings 1890, page 402), said that he had since gone forward with further applications of water-gas furnaces in the Sheffield district. The statements which he had previously made, in regard to the application of water-gas for crucible-steel melting, he was glad to be able now to say had been more than confirmed by the working of additional furnaces which he had

(Mr. R. N. Oakman.)

since constructed, in which 20 to 30 cwts. of small coal were now doing what required with coke firing from 50 to 70 cwts. of coke. In the latter case the consumption was about 3 lbs. of coke per pound of steel melted; and with water-gas this was now reduced to $1\frac{1}{2}$ lbs. of small coal, while the by-gas or producer-gas, obtained along with the water-gas, was not taken into account in favour of the result. In a tube-welding furnace just started the indications thus far obtained were that the economy in fuel would be about 40 per cent., and it might rise to 50 per cent. The economy in manipulation, the freedom from oxidation, and the much smaller percentage of waste of metal, would be the leading features in this mode of welding. These would be the first water-gas tube-welding furnaces erected in England.

With regard to the continuous regeneration of the air in furnaces fired with producer-gas, which was alluded to in the present paper (page 63), the producer-gas was used under pressure in all the furnaces which he had erected. From the producer the gas was delivered through a blower or exhauster into a gas-holder, which acted as a governor, being loaded so as to give a pressure of about three inches column of water; and it was thence delivered through pipes to the furnace. In this way, along with continuous regeneration of the air and gas, so perfect a control was secured by means of the chimney damper and by the regulation of the air valve, that with the producer-gas alone the heat could be raised to any temperature from 800° to 2,000° Fahr.—a result which was not easily attained with the ordinary continuous regenerative furnace.

In page 62 of the paper he observed it was stated that to some furnaces water-gas connections had been applied in addition to the producer-gas connections, in order that the two gases might be mixed. The two connections had certainly been provided, but they had not been used together; for while others were working with mixed gases, his own experience led him to believe that mixing the gases was hardly profitable, and that the greatest economy in fuel consumption depended on using either water-gas or producer-gas separately, according to the class of work to be done. Water-gas by itself should be utilised for the higher heats, and producer-gas for

the lower, both of them in the same works, but not for the same work.

Open-hearth steel-melting furnaces were perhaps those which interested engineers more than any other furnaces at the present time; and he hoped before long to have the pleasure of bringing before the Institution the working of the open-hearth furnaces of a new kind which were already in operation with water-gas in America, as well as of others now in course of being built on the Continent. A three-ton furnace in America was working with a consumption as low as 6 cwts. of fuel per ton of steel melted. A furnace of that capacity could be erected at a cost not exceeding £120 or £130. Other gas-furnace engineers who had had more experience than himself might perhaps agree with him in the anticipation which he entertained, that the time was not far distant when gas-furnace firing would be done with both gas and air under pressure.

Mr. A. H. REED considered it would be of interest if the author were able to give a few particulars as to the temperatures used in the different furnaces described in the paper; and if he would also state what pyrometer he considered suitable for some of the higher temperatures used, and what was the composition of the gas usually termed water-gas. He should be glad to hear a little more about the use of gas for boiler firing, as he happened to be interested in a simple arrangement which had been in use for some time in the United States, and of which a week's trial had just been made in London. It was the invention of Mr. E. B. Cornell, and consisted of a pair of retorts or cast-iron pipes of U shape, laid alongside each other, and connected at the ends of their adjacent legs so as to form a continuous length of retort, which was placed horizontally in the flue behind the furnace bridge. A small pipe from the steam dome delivered steam into the further end of the retort, in which it was first dried and then decomposed by the heat; and from the nearer end of the retort the gases were conveyed through a small pipe to an injector in the closed ash-pit. The jet of gases issuing from the injector drew in through it a certain quantity of air; and the mixed

(Mr. A. H. Reed.)

gases and air passing up through the fire-grate were burnt with the solid fuel of the fire. In the week's trial just completed of this apparatus it had been applied to two out of three cylindrical tubular boilers at the St. Katharine's Dock pumping station of the London and India Docks. The three boilers together supplied steam to the pumping engines feeding the accumulators for working the hydraulic appliances at the docks. There had been no opportunity of testing the quantity of water evaporated per pound of coke; but the record of fuel consumption showed that the engines had previously been making an average of 2,000 revolutions per chaldron of coke burnt. Under the same circumstances as regarded the dock routine and the working of the engines, it was found during the week's trial that the engines made 3,250 revolutions per chaldron of coke. It thus appeared that an economy of 38 per cent. in fuel was effected by the use of the apparatus; and further that two boilers with the apparatus attached were competent to do the work which had previously required three boilers. Similar results from the use of the apparatus were reported from different works in America.

Mr. J. MACFARLANE GRAY said the water-gas plan just described by Mr. Reed (page 77) had been submitted to his consideration some weeks ago, with a view to its being tried as had now been done. At first it had appeared to him to be like an attempt at perpetual motion; but after going into it he had found that it was slightly different. That it was so would be seen on considering that in a badly constructed furnace, from which a great quantity of heat that ought not to be lost was escaping up the chimney, it might be quite practicable to take hold of that heat at a place beyond where the heat already utilised had been caught; and if into that place could be put what had just been described as a retort, whether of cast-iron or of wrought-iron, into which steam was admitted from the boiler, it was stated by the inventor that the waste heat would decompose the steam, and the dissociated gases being brought back through a pipe into the furnace would there re-combine, and in so doing would give out the heat produced by their combination. The heat thus got in the furnace was no more

than the heat that had been picked up from the place where it ought not to have been escaping.

Mr. ROBERT BRUCE mentioned some stationary boilers near Glasgow, where the air for the supply of the furnace was heated by the waste gases. The air was driven by a fan through the pipes of the heater, in which it passed back along the flues of the boiler in the contrary direction to the chimney draught, whereby it was heated to a considerable temperature. Of this hot air a definite quantity was delivered into the ashpit, and the remainder into the furnace above the fire-bars. The result of the working of those boilers he had been told was a considerable saving in coal, due to the forced draught and the heat saved by the air from the waste gases. It was indeed an application of the well-known plan invented and arranged by Mr. Howden, which had been successfully used in marine boilers. From the instance he had mentioned it was apparent that there was still considerable economy to be obtained in ordinary boilers, by recovering much of the heat which was otherwise passing up the chimney to waste.

Mr. EDWARD B. MARTEN had had no experience in the working of boilers with gas specially made for the purpose, but a good deal of experience in Middlesbrough and other districts where the waste gases from blast-furnaces were used for boiler firing. He had been struck with the remarks made by Mr. Aspinall (page 67) and Mr. Dobson (page 68), that the gas-fired boilers had been found to suffer so much when they were made to do the right amount of work, but that when they were worked lightly they did not suffer, and answered well. What was the nature of the destruction of the boilers, or why they were so destroyed, he did not quite understand: whether the application of the gas was so unfair to the boiler as to do it a great deal of harm, or whether the gas specially made had some peculiar effect upon the iron; in other words, whether the gas was applied to the boiler in some awkward or trying way, or whether there was something in the gas itself which did the mischief. In reference to the short experiment with regard to the economy of using gas

(Mr. Edward B. Marten.)

under boilers on the plan described by Mr. Reed (page 77), of which it was stated there had been long experience in America, it would be interesting to know whether it had been found that the economy in the working of the boiler was at the expense of the boiler itself, and what was the effect upon the boiler. In working boilers with spent gases—a subject indeed having little to do with the present paper, which referred to gases specially made for the purpose—the difficulty was that the spent gases would sometimes supply an enormous quantity of heat, and the whole boiler would be bathed in a fierce flame; while perhaps the next hour it would be all different, and the same place would be occupied only by cold air and weak gas without flame; and the boiler would be so affected by sudden expansion and contraction as to wriggle on its seating. For these reasons so many of the long plain cylindrical boilers in the Middlesbrough district had suffered. Otherwise they were strong boilers, and were exceedingly convenient for the purpose; but the sudden great changes of heat in consequence of the gas being taken on or off destroyed them in a short time, and made them break in the middle. The difficulty of applying the heat of gas to boilers had always seemed to him to be that there was a fierce heat at one place while the rest of the boiler was doing comparatively nothing; and the result was that the hot part of the boiler soon wore out. If the gas could be employed over a much larger area, so that no part should be exposed to such a fierce heat, that difficulty might be overcome.

Mr. FREDERICK COLYER enquired whether gas firing had actually been applied to brewers' coppers in the manner shown in Figs. 39 and 40, Plate 16, and what had been the result, both as to the economy in cost of fuel over an ordinary coal furnace, and as to the time of boiling the copper. Also how were the flues arranged? and what kind of gas was used, and how produced? For what period had this kind of furnace been in operation for this purpose? It appeared to him that damage would be likely to occur to the bottom of the copper with the form of setting shown; it had been found by experience that, unless the lower part of the copper was protected all round the circular edge, it was soon burnt away; and as the bottom was made

all in one piece, it was a serious matter if any such injury took place. In most furnaces for coppers he had found in his own experience that it was material where the bridge at the end of the furnace was placed, as much injury had been done to copper bottoms by taking this much beyond the centre of the copper. With regard to the gas furnaces shown in Plate 17, for firing Lancashire boilers and also Babcock and Wilcox water-tube boilers, it would be interesting to know what was the economy effected in comparison with ordinary coal-firing; and whether the water was evaporated as rapidly as by an ordinary furnace, or more so.

Professor ALEXANDER B. W. KENNEDY, Vice-President, noticed that attention had been called by Mr. Head (page 71) to an interesting point with regard to the new Siemens furnace, namely that the gaseous fuel was there used while it was still hot, the gas being generated as near the furnace as possible, and carried into the furnace and mixed while hot with the air. Long ago it had been the view of Sir William Siemens, he believed—which however would no doubt have been modified, had he lived to the present day—that there was not only no disadvantage, but that there was an actual advantage in allowing the carbonic oxide to cool before it was taken through the regenerator. It was therefore interesting to know that in modern practice the gas might now be supplied direct to the furnace while hot, thereby saving so large a quantity of heat.

Though not himself engaged in iron making, he had been struck with some of the figures given in connection with the new Siemens puddling furnace (Iron and Steel Institute Journal, 1890 I, page 22), showing that the cost of coal per ton of iron made was only slightly greater than the cost of the furnace fettling per ton of puddled bars: so that the cost of fuel was now only about half the cost of the fuel and the fettling together, exclusive of the ordinary furnace repairs. This result enabled him to emphasize a point which he thought was not always borne in mind: namely that the successful use of gaseous fuel in certain metallurgical operations had really no direct bearing on the question whether it was worth while to use gaseous fuel under boilers, for the whole circumstances and

(Professor Alex. B. W. Kennedy.)

conditions were different. In gas furnaces such as the author had described for metallurgical purposes, the essential object generally was to obtain locally an extremely high temperature, and it was a necessary consequence of the process that the burnt gases left the furnace at a high temperature. The regenerators were therefore put in, because it could not be afforded to lose so large an amount of heat in the escaping gases. In the firing of a boiler the conditions were all altered: a high local temperature was not wanted, nor was there any necessity that the gases should go away hot. Although therefore it might be perfectly true that under certain circumstances gaseous fuel might be valuable for boiler firing, yet the great success which had attended the modern development of gas furnaces for metallurgical processes was not of itself any argument that similar furnaces would be useful for firing boilers. The latter was a point that required separate proof. Although he could conceive of conditions where it might be advantageous to use gaseous fuel for boilers, those conditions he thought must be somewhat far apart, and somewhat hard to find, occurring possibly with special fuels and special prices. The use of waste gases for firing boilers was another matter; but where gas would have to be made specially for the purpose of firing boilers, he was afraid that a great deal more disappointment would still ensue, as it had already ensued, from the mistaken notion that the economy of fuel obtained in iron and steel making, due no doubt to a great extent to the use of gaseous fuel, might be equally well obtained in a boiler furnace. The mistake was rendered palpable enough by putting the matter the other way round; for if a steel-melting furnace were fired without a regenerator, as a boiler was worked, its efficiency would be absurdly low, perhaps not more than 5 per cent.; whereas a boiler fired without a regenerator had an efficiency of at least 60, 65, or 70 per cent., and in good instances much more. The two cases therefore could not strictly be compared.

Mr. Edward B. Marten was reminded by Professor Kennedy's remarks that he had himself once gone into the question whether gaseous fuel could be made at one central station for working some

pumping engines in South Staffordshire, at some distance apart; and he had then satisfied himself that, although this could be done, yet, even if half the fuel could be thereby saved, the interest of the outlay upon the necessary plant would take all the profit away, and it would therefore be of no use to make the attempt.

Mr. DRUITT HALPIN thought Professor Kennedy had stated the matter mildly (page 82) in saying that in a steam-boiler furnace from 60 to 70 per cent. of the theoretical value could be got out of the fuel. In some of Professor Kennedy's own tests he believed 85 per cent. had been obtained; and the remaining 15 per cent. was legitimately used in the mechanical work of the draught. With these higher results, and remembering that 70 per cent. was readily obtained, he failed to see where there was room, even apart altogether from expenditure of capital, for anything like the saving of 50 per cent. which Mr. Marten had spoken of.

Mr. G. J. SNELUS believed he alone had had experience in the practical working of the hydraulic slide-valve mentioned in page 58 of the paper. It was a valve arranged by his late pupil, Mr. Foster, for the use of the Siemens furnace; and he had found it to be exceedingly valuable, inasmuch as it avoided the great waste of gas which he thought had generally been found to result from the butterfly valve first adopted by Sir William Siemens. In his experience extending over many years with a large number of gas furnaces, he had found it extremely difficult to keep the butterfly valve tight. It got heated and warped, and let the gas escape up the chimney; and unless it was constantly being repaired, the waste of gas was serious. Generally the waste escaped notice, because the valve was out of sight, and the workmen did not take much trouble with it, so that it was allowed to get into bad repair. Having examined some years ago all the valves then in use, he came to the conclusion that all of them were open to more or less objection. Finally he had made an experiment with the slide-valve as arranged by Mr. Foster for reversing by hydraulic pressure; but he had added to it a cooling arrangement in the casing, so as to prevent the slide

(Mr. G. J. Snelus.)

from warping or twisting or getting out of order. There was a great saving in the gas with the valve so arranged, and he found no difficulty at all with it, with the one small exception that when the valve was really out of use, and the furnace was allowed to go cold, a deposit of tar accumulated on the rubbing faces of the slide; and it was necessary to make provision for getting at both the back and the front of the valve, in order to clean it from time to time. While the valve was in use, there was no trouble with it whatever, because so long as it was warm there was no deposit of tar; but when the valve was cooling, a slight deposit of tar began to form on the back and front of the slide, which gradually accumulated and after a time gave some trouble. Its removal was no great difficulty; and with a slight modification of Mr. Foster's arrangement he believed that nothing better could be devised for the use of gas furnaces than that slide-valve. The double-beat Cornish valve was good, but it was never possible to be quite certain of its being home; but with a slide-valve it was known that the aperture was perfectly closed, and that no gas was wasting, so long as the valve was well made, and so long as the casing was kept cool by the circulation of water.

Among the different forms of gas furnaces described in the paper there was no reference to a furnace which in his recent visit to America he had found to be in extensive use there, namely the Lash furnace. It was used particularly where ordinary natural gas was employed; but he did not see any reason why the modification adopted for burning natural gas could not also be applied to ordinary producer-gas. The modification consisted in the position of the regenerators, which, instead of being placed underneath the furnace as in the ordinary Siemens plan, or alongside on the level ground as in some of the other arrangements, or above as in the Casson furnace, were placed at right angles to the furnace in the flues leading to the chimney. The regenerators were chambers about 30 feet long, 6 feet wide, and 6· feet high, which were filled with regenerator bricks. At the Homestead Steel Works in Pittsburgh, Pennsylvania, Mr. Andrew Carnegie had no less than sixteen 25-ton basic furnaces with the regenerators arranged after that fashion; nine of the furnaces were working at the time of his visit, and they were working

remarkably well. It had struck him that it was an exceedingly good arrangement of the regenerators to have them at right angles to the furnace, quite away from the furnace and on the road to the chimney; and he thought the plan was well worth mentioning.

Mr. JOHN HEAD mentioned that horizontal regenerators, placed at the same level as the heating chamber or slightly below it, had been devised by Mr. Frederick Siemens as long ago as 1856. The reversing slide-valve of Mr. Foster was said to be an excellent contrivance, and Mr. Snelus' favourable opinion of it was quite sufficient. But if the flap reversing valve was objected to, there was also the bell valve, which was used in France and Germany, though not so much in England; it was cooled by water, and it always kept tight and worked satisfactorily; it had the advantage that even when it was cold it would not go wrong.

Mr. DAWSON, in confirmation of Mr. Aspinall's experience as to the distance through which gas could be made to flow from the producer to the furnaces where it was used (page 68), said he had never found that any distance likely to be met with even in large works formed an effectual obstacle; during its passage below ground the gas did not lose anything appreciable either in temperature or in quality.

It was agreed by both Mr. Aspinall (page 67) and Mr. Dobson (page 68) that boilers fired with producer gas—that is, gas made specially for the purpose, and not waste gas from a blast-furnace—could not be forced. In this connection it might be well to point out that, where there were only one or two boilers, these must be depended upon for supplying the steam required to drive the gas producers. But if there were a number of boilers, the best thing to do was to have a small independent boiler to drive the gas producers; because if the main boilers themselves had to supply the producers, and a careless fireman filled them all up with water, down went the pressure, and down went also the volume of steam supplied to the producer, just when an increased supply of gas was wanted in order to get rid of the effect of the cold water that had been introduced. The same

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applied to boilers in dye works and breweries and for working steam hammers, all of which were liable to sudden demands from time to time. In a dye works with which he was acquainted at the East End of London there were five Lancashire boilers, and it had been found advisable to disconnect two of them by means of stop-cocks and steam-valves; and whenever the attendant found that there was a sudden demand on the steam in the other boilers, he kept these two boilers at full pressure to supply the gas producers, and forced the three other boilers on, which there was no difficulty at all in doing by means of the steam in the two boilers that were kept at full pressure. With the limited experience which he, like so many others, had at present had in the direction of applying gas to boilers, he had never before heard the objection, raised by Mr. Aspinall and Mr. Dobson, that it was impossible to force boilers fired with gas. If the boilers could be worked at a proper pressure and at a proper rate by a certain quantity of gas burnt thoroughly, he agreed that, on any attempt to force them with more gas than they could burn, down would go the pressure, and there would be smoke from the top of the chimney. But if a gas-fired boiler could not be worked so as to get a proper result from it, that was probably owing to a defective arrangement, such as the excessive introduction of air, or some defect in the combustion, or in the mixing chamber outside the boiler; or else to a neglect in preventing in some way the ignited gas from impinging on a comparatively small surface of the boiler. On various occasions attention had been called by Mr. Head to the fact that it was necessary to ensure complete combustion of gas inside the boiler furnace, before allowing it to impinge upon the cold surface of the tube or flue beyond; because wherever incompletely burnt gas impinged upon the cold surface of the tube or flue it deposited soot, and also cooled below the temperature of ignition. Notwithstanding the opinion expressed by Mr. Aspinall and Mr. Dobson, he thought that there were tests published by Mr. D. K. Clark and others, which had shown that it was possible to obtain a greater duty from a gas-fired boiler under normal conditions than could be obtained from coal firing with the same class of coal. In confirmation of this view he believed it had been found by analysis

that the escaping gases in the chimney flues of boilers fired with gas contained a higher percentage of carbonic acid than when the boilers were hand-fired with coal.

When Mr. Casson showed him the open-hearth steel-melting furnace at Round Oak, he saw two producers, both of which were then working; and he therefore imagined that was the normal condition, having himself no knowledge of the working of the furnace. It had now been explained (page 72) that the furnace was worked with one producer instead of two.

Some of the diagrams illustrating the paper represented failures (page 68), to which he had alluded in connection with the blow-pipe and other furnaces; and he thought the members would agree with him that it was sometimes advantageous to show what had failed, as well as what had succeeded. Useful lessons could be learned from failures; and possibly there were few engineers who had carried out gas-furnace installations, who had had more experience of failures than himself, and also of the best means of remedying them and converting them into successes. It was well known that even the furnaces erected by Messrs. Siemens had not all been attended with unqualified success. There were several furnaces which had been at work in the country for some years; and yet, owing to the inexperience or obstinacy or prejudice of the men, it had sometimes been impossible to give exactly similar gas-fired furnaces a fair chance with coal-fired furnaces doing the same work. It had been said that as a rule it was scarcely worth while to work gas furnaces, unless fuel could thereby be saved. Often it was so; but there were places where the difficulty of getting fuel from the railway siding or the canal bank to all the furnaces in a large works might be such as to make it worth while to apply gaseous fuel to furnaces, vats, and boilers, when the cost was in itself a secondary object.

With regard to cooling down the temperature of the furnace effluent gases too low to ensure sufficient chimney draught, he could not agree with Mr. Head (page 69) that it was only necessary to build a higher chimney in order to obtain draught enough. That might be so with reversing regenerative furnaces; but with continuous-

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regeneration furnaces the difficulty was to get such a draught as would induce the air to enter the furnace, without at the same time pulling the gas unburnt up the chimney. If the gas were forced in by the steam-jet which actuated the gas producer, there was nothing to induce the air to enter the furnace except the chimney draught.

With regard to leakage through the joints of the fire-brick tubes in the Radcliffe furnace (page 70), some time ago he had been consulted as to whether it was advisable to work a Radcliffe furnace in Sheffield; and he accordingly went to Woolwich, and saw all who were concerned in the working of the Radcliffe furnaces there, both in the gun factory and in the laboratory. They had assured him that, although the difficulty of leakage through the joints of the fire-clay tubes was hardly imaginary, it was scarcely worth consideration; and he had been surprised to find that the joints stood as well as they did.

As a general principle furnaces that had only two regenerators had been condemned by Mr. Head (page 69), who however had then called attention to the new Siemens furnace with only two regenerators (page 71).

Allusion had been made by Mr. Casson (page 73) to the difficulty he had found with lime or some other material sooting up the regenerators. From his own experience of the working of other basic furnaces, that difficulty was not confined to the furnace at Round Oak. All regenerators were liable to it. All the regenerators of the ordinary Siemens kind got choked up with slag, which was run down from the brickwork itself in the passages leading from the furnace to the regenerator. That difficulty of course would not occur with regenerators placed above the furnace. But the difficulty of blocking up with lime dust the chequer work in the regenerators of basic furnaces was due to the fact that in most of such furnaces a shovelful more or less of powdered lime was introduced at some period of the charge; and the chimney draught on the furnace carried a portion of that hot powdered lime direct into the regenerators at a high temperature, and the lime fluxed there upon the chequer work of the regenerators, whether the chequer work was built of fire-bricks or of silica. If the lime were supplied into the furnace in the form

of nuts or cobbles, he thought no more trouble would occur from its choking the chequer work with light dust carried from the furnace.

Although Mr. Slater had spoken of his experience as so limited with regard to the new Siemens furnace at his works (page 74), it should be remembered that few others could have had a much longer experience, because the furnace had been introduced only a short time ago.

The low cost of water-gas furnaces for carrying out many of the processes to which producer-gas had hitherto been exclusively applied had been spoken of by Mr. Oakman (page 77). To himself so low a cost was astonishing; but having had no personal experience of the furnaces described, he could not point out how it was that such good results could be attained at such a low cost in the matter of construction and erection.

The composition of water-gas (page 77) was a matter of technical analytical chemistry; and for information in regard to it therefore he preferred to refer to some of the makers or users of water-gas, or to some of their published statements about it.

As to the pyrometer he recommended for testing the temperature of the furnaces (page 77), he was sorry to say he had never yet had a pyrometer which either returned to zero when it was taken out of the furnace, or did not want a fresh constant of error worked out for it every time it was used, before its indications could be relied upon. During his own experience some years ago in the working of blast-furnaces, he had never met with a pyrometer that could not also be cooked, according to the wish of the furnace manager, in order to show the temperature at which he was directed to maintain the hot blast; this was the case alike with the Gauntlett, the Hobson, and the Siemens pyrometer. As to the actual temperatures inside the furnaces, in the absence of any reliable pyrometer he was sorry that he could give no information. Many books had been published giving the melting temperatures of steel, copper, and nickel; and to those he must refer.

With regard to firing boilers by gas, this was not quite such a new thing as was sometimes imagined. There were hundreds of

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boilers fired by gas in the Cleveland and other districts where there were bell-topped blast-furnaces, from which the gas was taken off for heating the blast and raising steam ; but that was not quite the same case as the firing of boilers with producer-gas, because nearly all the boilers fired with blast-furnace gas were fired with gas made from coke, whereas boilers fired with producer-gas were fired with gas made from coal. The difference however was not so great as to render boiler-firing with producer-gas so entirely a matter of experiment as seemed to be sometimes supposed. Some years ago he had conducted at Swindon an experiment for Mr. Dean as to the relative quantity of water that could be evaporated from a boiler of the locomotive type, by hand-firing with coal and by firing with gas made from the same coal, both with and without the ordinary brick arch in each case. The result of hand-firing with coal he could not remember ; but in gas-firing with the producer worked with the greatest care he did remember that the maximum efficiency attained was $8\frac{1}{3}$ lbs. of water evaporated by 1 lb. of small dirty South Wales bituminous coal. The difficulty of gas-firing in a boiler of the locomotive type was that before the producer-gas flame had got 8 or 9 inches along the tubes, or under the best circumstances perhaps 2 or 3 feet, it went out, and all the further heating power of the gas was gone. With water-tube boilers, in which the gas was circulating round the outside of the tubes, the result was much better. With water-tube boilers of the kind shown in Figs. 43 and 44, Plate 17, he believed that the best results attained with gas-firing showed an economy of about 17 per cent. over hand-firing with coal. It was only right to say that where this economy had been attained the hand-firing had been of a bad character before. In most of the comparative statements made about the superiority of gas-firing over hand-firing with coal it was omitted to be mentioned how well or how badly the coal-firing which the gas had superseded had been done. The best evaporation of which he had heard in water-tube boilers with producer-gas was about $11\frac{1}{2}$ lbs. of water per lb. of coal, evaporated from 212° Fahr. He did not vouch for the accuracy of the statements ; but they had been given him by the users of gas-fired boilers. The stationary boilers near Glasgow, worked with heated

air and a forced draught, which had been mentioned by Mr. Bruce (page 79), scarcely came within the province of gas-firing. The irregular supply of blast-furnace gas to the old-fashioned plain cylindrical egg-ended boilers from 70 to 90 feet long, which were formerly employed in the Cleveland district, had been mentioned by Mr. Marten (page 80); they used to go on arching up and down in the middle of their length until something gave way, usually one of the seams; and disastrous explosions had resulted from that action, which was supposed to be due to the irregular supply of gas. No one he imagined would now attempt to employ egg-ended boilers of so great a length for firing with producer-gas. In firing Lancashire or Cornish or water-tube boilers with gas, he did not think there would be any trouble from slight irregularities in the supply furnished by the producer. He wished to take this opportunity of thanking Professor Kennedy for putting into a more concise and terse form than he had ever heard it put in before (page 82) the distinction between the waste-gas temperature from boilers and from other furnaces; his remarks were most valuable for dispelling the notion that boilers should be fired with gas under the same circumstances as regenerative furnaces.

Brewers' coppers, about which Mr. Colyer had asked (page 80), had been set in different ways; they were more generally set with the old-fashioned wheel flue, as shown for gas-firing in Figs. 39 and 40, Plate 16. The gas was ordinary producer-gas, made from Derbyshire small coal; and the system had been employed for several years. In this instance it would be seen that there was also continuous regeneration of the air entering through a flue beneath the firing chamber. The illustration in Plate 16 was from a drawing lent from Messrs. Fremlin's pale-ale brewery at Maidstone, where first one copper had been tried, and then several more; and they were now increasing the number of their gas-producers with a view to firing the whole of their coppers with gas. He had never heard from them that there had been any trouble with the thin coppers in regard to their standing the impact of the flame where it struck direct upon them; if there had been any such trouble, he should have been sure to hear of it.

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Of Mr. Foster's hydraulic slide-valves, referred to by Mr. Snelus (page 83), the only examples which he had seen were at West Hartlepool, where they seemed to be doing well. They were no doubt costly, and in some places they might not be applicable, because it was not everywhere that accumulators were available for giving the hydraulic pressure necessary to reverse the valves. There were troubles with various sorts of valves from warping, but he had never heard that the Foster valves had given trouble in that respect.

With respect to the Lash furnace (page 84), he had endeavoured to get information from the United States about it, in order to ascertain how far it might be suitable for producer-gas as well as for natural gas; but up to the present time he had not succeeded in doing so. In regard to furnaces with horizontal regenerators, it would be remembered that the ordinary horse-shoe type of furnace had for years past always been arranged with horizontal regenerators. Furnaces worked on that principle he believed had been constructed in Barnsley not long ago; and he understood the furnaces of horse-shoe type were giving excellent results as far as gas-firing went. There were other furnaces for working glass and nickel, which were also arranged with regenerators like the ordinary horse-shoe type of furnace.

With regard to the expediency of reversing regenerators for firing boilers, a great many reversing regenerative furnaces for firing boilers had been erected in different parts of Germany; but he believed the general opinion arrived at was that they did not justify their cost and their complication. Considering the one point which affected the economy of working a boiler, namely that the waste gas should leave at a low temperature, he could not conceive how under any circumstances it could be worth while either to put an excessive quantity of gas into the boiler furnace or to heat the gas to the high temperature obtained with reversing regenerators; nor on the other hand ought there to be sufficient unburnt gas or sufficient waste heat coming out of the boiler furnace to be worth while passing it through the reversing regenerators. With the exception of a few cases he believed all the regenerative gas-fired boiler furnaces had been abandoned.

The PRESIDENT proposed a cordial vote of thanks to Mr. Dawson for his highly interesting and comprehensive paper, which had elicited so much discussion and would he was sure prove most valuable to engineers generally. It was of as much importance to know what not to do, as what to do ; and throughout his own work he had always endeavoured to find out first what had been tried and had failed, and so to avoid the failures, not wasting time by going again over the same ground. He would take the opportunity of adding how entirely he concurred with Professor Kennedy's remarks about gas-firing for boilers (page 82), which expressed his own views as fully as he could have done himself.

ON THE MECHANICAL TREATMENT OF MOULDING SAND.

BY MR. WALTER BAGSHAW, OF BATLEY.

Literature on the art of Founding and on the materials employed in the Moulding of iron, steel, and brass, is unfortunately scanty, owing no doubt partly to the lack of the same personal interest in the foundry that is taken in other departments of engineering works; and in a large number of instances this want of familiarity with foundry practice causes the production of castings to depend on the experience of individual workmen. If a waster casting be the result, it is invariably and not unnaturally attributed to accident, when it may be more probably due to want of skill; for even moulders themselves are not generally credited with a scientific knowledge of the principles on which their art depends. In large shops there is of course a competent foreman, who is responsible for the execution of orders in the most economical way; whereas in smaller foundries, even important work, such as the preparation of cores and mixture of sand, is not infrequently carried out by unskilled workmen in a rather empiric manner. On the subject of the present paper there seems to be as much difference of opinion as there is diversity in practice; the writer therefore hopes discussion may help to settle debatable points. Some moulders place faith only in kneading or treading the few simple materials composing their facing sand, jealously guarding the preparation as a trade secret, and condemning all machine work; whilst others are equally emphatic in favour of the particular machine for grinding, riddling, or combing, to which they have been accustomed.

Sand.—Before describing the foundry processes in use it may be interesting to examine specimens of the ingredients generally incorporated.

Fig. 1, Plate 25, is a view, magnified 50 diameters, of sand found and much used in the West Riding of Yorkshire. In its natural state it will be noticed that a portion of the grains adhere together in clusters, varying in size from masses containing hundreds of sand grains to smaller groups of three or four grains, most of them small enough to pass through an ordinary fine riddle without disintegration. The form and size of the groups are very irregular, and many are covered with a fine scaly powder. Samples from the bulk show a preponderance of grain groups devoid of any uniformity. There are exactly the same appearances in fine Mansfield and other sands, though the presence of sharp crystals may be more frequent, and the abraded corners not so conspicuous.

Fig. 2, Plate 25, represents new sand mixed with coal dust and burnt sand. The dark spots dotted over the new grains are particles of coal which attach themselves in this manner, and when subjected to the heat of molten metal are converted into coke, often enveloping the sand grain with a crust, as shown in Figs. 3, 4, and 6, Plate 26. In none of the specimens examined was coal found in a separate loose state.

Figs. 3 and 4, Plate 26, show samples of old sand very much like gas coke, with perhaps more of a metallic lustre.

Fig. 5 shows the extent to which sand may be destroyed by burning or chemical action. Numbers of these friable hollow husks occur in a more or less broken condition, and are easily reduced to fine powder by concussion with other particles. If used again in sufficient quantity, they will cake and cause metal to boil.

Fig. 6 illustrates the formation of a shell round a sand grain; the shell may be cracked like a nut, exposing a kernel of clean sand.

Coal dust, as commonly found, takes the form of angular splinters with laminated surfaces. When magnified 50 diameters, Fig. 7, Plate 26, it appears only like a fine powder; the larger pieces are not present in quantities, if the coal has been properly ground.

These materials after incorporation are generally coated with some other substance, plumbago being the most preferred; but it is difficult to give a correct impression of this article in a drawing. The flakes shown in Fig. 8, Plate 26, are taken from a surface polished

with black lead, presenting to the naked eye merely its own peculiar lustre over a large area. When viewed in bulk it is fluffy, like soot; and the outlines of separate flakes are not well defined by the prevailing light and shade.

The chemical composition of sand will obviously affect the nature of the casting, no matter what treatment it undergoes. Stated generally, good sand is composed of 94 parts silica, 5 parts alumina, and traces of magnesia and oxide of iron. Sand containing much of the metallic oxides, especially lime, is to be avoided.

Geographical position is the chief factor governing the selection of sand; and whether weak or strong, its deficiencies are made up for by the skill of the moulder. For this reason the same sand is often used for both heavy and light castings, the proportion of coal varying according to the nature of the casting.

A common mixture of facing sand consists of six parts by weight of old sand, four of new sand, and one of coal dust. Floor sand requires only half the above proportions of new sand and coal dust to renew it. German founders adopt one part by measure of new sand to two of old sand; to which is added coal dust in the proportion of one-tenth of the bulk for large castings, and one-twentieth for small castings. A few founders mix street sweepings with the coal, in order to get porosity when the metal in the mould is likely to be a long time before setting.

Plumbago is effective in preventing destruction of the sand; but owing to its refractory nature it must not be dusted on in such quantities as to close the pores and prevent free exit of the gases. Powdered French chalk, soapstone, and other substances are sometimes used for facing the mould; but next to plumbago, oak charcoal takes the best place, notwithstanding its liability to float occasionally and give a rough casting.

Hand Riddling and Treading.—For the treatment of sand in the moulding shop, the most primitive method is that of hand riddling and treading. Here the materials are roughly proportioned by volume, and riddled over an iron plate in a flat heap, where the mixture is trodden into a cake by stamping with the feet; it is turned

over with the shovel, and the process repeated. There is no doubt that tough sand can be obtained in this manner, its toughness being usually tested by squeezing a handful into a ball and then breaking it; but the process is very slow and tedious, and consequently expensive if tried on a large scale. Other things being equal, the chief characteristics of a good moulding sand are toughness and porosity, qualities that depend on the manner of mixing as well as on uniform ramming; indeed the same result would follow from want of attention to the one as to the other. For instance it is well known that a mould rammed too tightly in one place and loosely in another will cause a swelled uneven surface on the casting. Similarly if quantities of fat sand and poor sand occur alternately through improper mixture, the power of resisting the pressure of the molten metal is not equal, apart from the liability of causing the metal to scab; and a wavy rough surface will be the consequence, as in the casting exhibited from improperly mixed sand. Another casting shows the effect of loose coal-dust on the skin of the metal. In America a moulder will often prepare his own sand by hand riddling and treading, rather than have it put through a machine. For the pneumatic method of moulding with compressed air and flexible pressure-plate it is claimed that it gives sand of uniform density at all points equidistant from the pattern; yet in this system, as in hand moulding, the thorough mixture of the sand is of the first importance. The practice of piercing the mould with a vent rod will never give results equal to those realised with sand having its ingredients properly incorporated.

Power Riddling.—It is only a step from hand riddling to power riddling; and the latter has been made to approach as nearly as possible to the former by a succession of impulsive movements for the purpose of opening out the sand. Usually a power riddle, as shown in Fig. 10, Plate 27, consists of a set of transverse horizontal bars called breakers, placed over a coarse riddle, below which again is a fine riddle, the whole being set slightly sloping downwards towards the outer end. Lumps that do not pass through these roll off into a heap at the lower end. The frame carrying the bars and riddles is

suspended from straps, and oscillated by a crank or cam at a speed of 120 to 140 revolutions per minute. For quantity, this mode of mixing is a decided advance on the slow hand-process, though it presents the objection of not opening out the groups of grains.

Roller Mill.—Another means of treating sand is the roller mill, Fig. 11, Plate 27, which is said to answer very well for hard sand containing stone. With soft sand the writer's experience has not been favourable to rolling, inasmuch as the castings made with sand so treated show a strong tendency to scab; but other founders state they do not find any serious disadvantage from its use. Viewed through a microscope the effect of slight pressure on sand would tend to confirm the writer's opinion; sand was placed between two slips of glass on the microscope stage, and a gentle sliding movement being given to the upper slip by the thumb of one hand, the rounded grains were seen to fly asunder into sharp crystalline forms, as depicted in Fig. 9, Plate 26. It is true that only those grains in immediate contact with the rollers would be thus violently acted upon, the rest forming a cushion; yet the former must be a considerable percentage of the whole quantity. If all the sand were actually crushed, the result would be the reverse of beneficial, for it would be too fine, and the fragments would form so close and dense a mass as to render it impervious to gas.

Centrifugal Mixer.—Schütze's centrifugal mixer, shown in Figs. 12 to 14, Plates 28 and 29, combines the advantages of all the other plans, besides giving a considerably greater output of sand. The particles of clay or groups of sand grains are so thoroughly disintegrated and mixed with the coal dust that the gas generated in the mould can get round every particle of sand, and so escape easily and equably, which is a desideratum for a fine casting. Agglomerated sand in large lumps, too big to pass through any riddle, comes out of the centrifugal mixer in a fine powdery condition along with the other materials; consequently no previous sifting is required. In ordinary work the materials are placed in layers, sandwich fashion, on the floor, in a convenient position for being shovelled into the hopper

of the machine, through which they are passed as fast as two men can shovel them in. The actual quantity thus mixed is at the rate of twelve tons per hour, or a ton in five minutes.

The action of the machine will be readily understood. The revolving table T, Plate 28, is mounted on the top of a vertical spindle P, and carries on its upper face a number of vertical pins or beaters, fixed alternately in a series of concentric circles, Fig. 12. The table is driven by a 3-inch belt, Fig. 14, Plate 29, at the rate of 1,200 revolutions per minute. The cover of the table has a hinge for turning it up in order to allow pieces of metal or other foreign substances to be readily taken out, which can be done at any time in only a few minutes. Falling upon the centre of the table from the hopper above, the sand is projected at a great speed from one row of pins to the next, until every part has been combed out. Round the outside of the table an india-rubber shield S guides the sand into a circular heap after it has been whirled from the table.

Moulds made with riddled sand and with sand mixed by this centrifugal machine—one half of the mould being made with each kind—certainly induce a preference for the machine mixing, after examination of the skin on the casting. Moreover with the machine one man can do the work of several in the preparation of the sand, thus securing economy in time and wages.

This machine was first seen by the writer when in Germany, where there are four hundred now at work; and he was so much struck with its simplicity and efficiency that he ordered one for his own works, and found the result of its adoption to be a great saving in wages and better work. The prejudice however in favour of existing methods is so great that few other works in England have as yet ventured to adopt it. In response to enquiries concerning the cost of mixing sand by hand labour and by machine, only two firms out of twenty applied to could give any estimate. Longer life of the sand is ensured by the complete intermixing of the materials; the reason for this may be seen in the protecting coat or shell shown in Fig. 6, Plate 26. Moreover a more even surface must result from the fact that, while the clay in the sand contracts under heat, the coal expands. A workman's ready method of testing the admixture of coal dust is to

take a handful of the sand and rub it briskly over his shovel handle for a few seconds, whereby the coal on the surface becomes burnished, and presents to the eye a more or less uniform brightness, from which quantity and equality may be judged.

Toughness of Sand.—In order to test the relative toughness, sand mixed in various ways was pressed under a uniform load into bars 1 inch square and about 12 inches long, and each bar was made to project further and further over the edge of a table until its end broke off by its own weight. Old sand from the shop floor had very irregular cohesion, breaking at all lengths of projection from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches. New sand in its natural state held together until an overhang of $2\frac{3}{4}$ inches was reached. A mixture of old sand, new sand, and coal dust—

mixed under rollers, broke at 2 to $2\frac{1}{4}$ inches of overhang.
„ in the centrifugal machine „ 2 „ $2\frac{1}{4}$ „
„ through a riddle „ $1\frac{3}{4}$ „ $2\frac{1}{8}$ „

showing as a mean of the tests only slight differences between the last three methods, but in favour of machine work. In many instances the fractures were most uneven, so that minute measurements were not taken.

Tests for porosity were also made by putting the various sands into a tube, and forcing air through. These however have no practical value, because the conditions when in contact with molten metal are quite different.

Working Expenses.—Although the centrifugal machine will actually mix twelve tons per hour, it is not assumed that this quantity would be passed through it continuously; therefore a moderate estimate of only thirty tons per day is taken in the following data. The power will of course vary with the work. No dynamometrical test has yet been made with the machine working to its full capacity; the power is calculated from the belt, and a belt of an inch width running on the fast pulley will suffice. A machine in Devonport Dockyard takes one horse-power when mixing two tons per hour, or about half the power allowed in the following estimate:—

Mixing 30 tons per day.	s.	d.
One labourer for 9 hours	4	0
3 horse-power for 9 hours	1	1½
Depreciation 10 per cent. on £33 for 300 working days per year . . .		2½
Repairs 5 per cent.		1¼
Interest 5 per cent.		1¼
Total per day. .	5	6½

The cost per ton is therefore a little more than twopence. Messrs. Marshall Sons and Co., Gainsborough, have three men employed on one machine to mix sand for 150 moulders and 14 moulding machines; but eventually their system will reduce this to one man's work. Other firms find one man working 9 hours per day can serve 30 moulders.

Equivalent Hand-Labour, &c.—The average output in riddling and treading sand is 4 cwts. per hour per man, which with wages at 5*d.* per hour gives 2*s.* 1*d.* as the cost per ton, or twelve times more than by the centrifugal machine. As no exact cost of mixing sand by other systems at present in use could be ascertained, no allowance is made for power, depreciation, and repairs; for wages only the cost of mixing by power riddling amounts to 1*s.* 3*d.* per ton, and by rollers to 1*s.*

Durability.—After two years' working of the centrifugal mixer, no expense of any kind has yet been incurred for repairs. The working parts are so few that the cost of maintenance leaves nothing to be desired.

Discussion.

Mr. BAGSHAW said that both at the previous meeting, from which the reading of the paper had been adjourned, and also on the present occasion, he was indebted to the kindness of Messrs. R. and J. Beck for lending a large number of their microscopes, under which could be examined specimens of moulding sand and of the various ingredients composing it, in confirmation of the magnified illustrations shown in the drawings, Figs. 1 to 9, Plates 25 and 26. He also showed a collection of samples of moulding sand and of the materials used; and specimens both new and worn of the pins or beaters in the centrifugal mixer.

Mr. JAMES PLATT said the custom had gone out of fashion for apprentices to spend part of their time in the foundry; at any rate it was not so general now as it was forty years ago. All the more therefore was the paper an interesting one; and it was well illustrated by the magnified drawings shown of the materials. Doubtless many engineers would be surprised to see the forms that moulding sand assumed under the microscope; but on consideration it was obvious that the sand must be composed of particles or grains of stone, coal, and other ingredients, to make it cohesive or fibrous. The riddle and the rollers or revolving runners were of course in general use; but the centrifugal mixer was not yet so generally used. Having seen it at work he believed it was an admirable machine; it certainly got through an astonishing amount of work, and mixed the sand in the right way. The feel of the sand so mixed was very much like that of the sand mixed by treading. The effect of the wear and tear of the pins could be seen from the specimen exhibited, showing with how great force the sand was thrown about in the machine, which much resembled Carr's disintegrator (Proceedings 1872, page 28).

Mr. JOHN G. MAIR-RUMLEY, Member of Council, said that formerly all the riddling and mixing of moulding sand had been done by hand. It was about twelve years ago that a pair of Hetherington's power riddles for riddling sand had first been put up at Messrs. Simpson's

works. After the sand had been riddled, there was the question of mixing it. It used to be mixed by hand, until the roller-mill was used; but it had been found that the use of the ordinary roller-mill with plain rollers, employed for mixing loam, made the sand so close that the mould could not be vented properly. Therefore, instead of rollers with a plain face, rollers with a grooved or serrated face were substituted, the serrations extending about six inches up, so that the rollers then merely mixed the sand, instead of grinding it. It was found that one man could attend to the riddle and also throw into the roller-mill sufficient sand for thirty or forty moulders, which was about the same that could be done with the centrifugal mixer. The reason he thought was that the sand he was using was of a rather different character, and did not want quite so much riddling and mixing as that described in the paper. In pages 95 and 96 reference had been made to dusting the mould with plumbago. That was undoubtedly an excellent plan for preventing destruction of the sand; and another important advantage was that the plumbago enabled the casting to be fettled or cleaned much more readily, especially some of the larger castings. If a properly made wash of plumbago were put on the face of the mould, it could all be cleaned off the casting with the scab, and would leave a clean surface underneath. It was astonishing what a difference there was between various sands. When visiting a foundry in America he had seen the making of cores with a peculiar sand, far coarser than what was here called loam but what was really coarse sand. They were small cores, made of a great length without any wires, and a peculiar kind of core-gum was used, which was much stronger than any used here. The sand grains were remarkably large, some nearly up to 1-8th inch diameter, and most of them certainly over 1-16th inch; and they were all cemented together by the core-gum. He had endeavoured to get sand like it in this country, but had not been able to do so.

Mr. BENJAMIN BROWN, referring to the statement (page 99) that longer life of the sand was ensured by the complete intermixing of the materials, asked whether it was meant that more of the old sand could be used in the mixture of facing sand; and if so, how much more.

Mr. J. W. WILSON, JUN., mentioned that he had visited Messrs. Cochrane's works at Dudley shortly after one of these machines had been introduced there. At that time certainly the manager, Mr. Houghton, was pleased with the working of the machine. It was stated in the concluding paragraph of the paper (page 101) that after two years' working of the centrifugal mixer no expense of any kind had yet been incurred for repairs. Mr. Houghton however had pointed out to him that even at that early stage a number of the pins had commenced to wear rapidly, and in an irregular manner. Some of the pins in the inner circles had thus deteriorated to a remarkable extent, and apparently without any method as regarded their position; and then perhaps in the next circle or the next but one, the pins showed an equally remarkable extent of wear in quite a different part of the circumference.

Mr. CHARLES COCHRANE, Past-President, being prevented from attending the meeting as he had intended to do, wrote that one of these machines had been in use for many months past at the Woodside Iron Works, Dudley, and was giving unqualified satisfaction.

As to the quantity of sand it is capable of disintegrating, a special test was made there in October last, in which there was weighed a mixture consisting of:—sand 1·087 ton, coal dust 0·119 ton; making a total of 1·206 ton. In six minutes the whole of this mixture passed through the machine in perfect condition for the moulder: thus confirming the statement in page 99 that the machine can turn out a ton in five minutes. Before the machine was employed, a staff of four men was needed at a total cost of 11*s.* 6*d.* per day for mixing by hand sufficient to supply about fifty moulders; nor could four men always meet the demand, and it sometimes happened that moulders had to leave their work and help to mix their own sand. Since the machine has been introduced, at a cost of 6*s.* per day for labour, the whole of the fifty moulders are now supplied; and not only the moulders, but the core-makers and workers in loam are supplied with pulverised loam: the newly ground loam, fresh and wet from the loam mill, is superficially dried in a stove, mixed with a proportion of old, and passed through the machine, with saving of

time and improvement in the character of the work. The machine has been sufficiently long at work to show that the working expenses must indeed be insignificant.

On the other hand there is no prospect of the wrought-iron pins of the centrifugal mixer lasting the two years referred to under the head of durability in page 101. These wrought-iron pins stand $2\frac{1}{2}$ inches above the disc, and are $\frac{5}{8}$ inch diameter; some of them are reduced to half their original diameter in three weeks at half-day work. There is something curious about the irregularity of their wear and tear, as illustrated in Fig. 15, Plate 29. It will here be noticed that they are not arranged strictly as described in page 99, "*alternately* in a series of concentric circles." The concentric circles are there, it is true; but with the exception of four radial lines of pins or beaters, dividing the disc into four quadrants, no law can be traced in the spacing of the studs filling up the concentric rings of each quadrantal segment. In the third, fourth, and fifth exterior circles it will be noticed there are fourteen pins shown black, which are much undercut after three weeks' wear, as shown in Fig. 16; the wear takes place on the face fronting the direction of motion in the circle of revolution. In the same three circles seventeen beaters marked with a cross + exhibit moderate wear; whilst the whole of the remaining pins show no wear of any notice. Obviously it must be an undue proportion of sand impinging on the worn pins of the three outer rings which occasions their extra wear; but why the special currents should take special directions in these cases, the writer confesses he is unable at present to explain. All he desires to indicate is that a hap-hazard arrangement of the pins must inevitably lead to such irregularities; and that by a scientific study and arrangement of the beaters this slightly objectionable feature in the machine may be removed, and the durability of the pins rendered uniform over the entire disc, and the machine made more efficient. It will probably have occurred to the author of the paper to substitute steel pins for wrought-iron, as a further step towards prolonging their life.

One other suggestion the writer would offer, to prevent accident. The attendant has no means of stopping the machine promptly, when desiring to cleanse it, or to cleanse the lid when thrown back. In

(Mr. Charles Cochrane.)

the former case he is obliged to wait till the machine stops; in the latter he proceeds to cleanse the lid, whilst the disc is revolving at diminishing speed beneath his hands and arms. Were he to trip or meet with any trifling accident which should throw either or both of his hands on to the revolving disc of beaters, his fingers must be fearfully crushed and broken. A light brake would meet this drawback to the high merits of a machine, than which the writer does not know a more useful one to have been introduced to a founder's notice for many years past.

Mr. BAGSHAW said Mr. Cochrane's letter was highly gratifying to him, for he had been a little afraid of over-stating the merits of the machine; and he was glad to find he had not done so. With reference to the undercutting of the pins, the specimen shown of a worn pin had been taken from the machine at his own works which had been in operation for three years; he had not been able to find a worse sample than this, and it would be seen how slight the wear was. From enquiries which he had made at several places where the machines were in operation, he had not learnt that the pins had been undercut to anything like the extent experienced by Mr. Cochrane.

In regard to the suggestion of adding a brake (page 106) he had asked the man who minded the machine at his own works whether a brake would be of any advantage; and he had told him that on stopping the machine suddenly the belt always flew off, so that he preferred to work the machine without a brake. It was simply a matter of precaution. No attempt was made to clean the machine until it was stationary.

With regard to the longer life of the old sand (page 103), all he meant to say in the paper (page 99) was that the floor-sand was renewed more seldom when mixed by the centrifugal machine than when mixed in the ordinary way.

In one instance he had heard a large employer of labour argue that, if he were to adopt every labour-saving appliance, every fuel economizer, and every other contrivance for effecting economy, he should be able, according to the representations made of their

several advantages, to carry on his works for nothing; and therefore he did not care to enquire into the merits of the centrifugal mixer or any other machine. Facts however spoke for themselves; and without wishing to over-rate the value of this machine, he thought the economy it effected in wages was so great as to render it deserving of careful consideration.

The PRESIDENT said this paper was of an interesting and practical character. Any idea of adopting improvements to the extent of saving everything was of course radically absurd; but he thought there was undoubtedly a great advantage in the centrifugal mixer now described, which as already pointed out was on the same principle as Carr's disintegrator. If the sand could thereby be brought to a uniform texture for the foundry, that was no doubt a condition conducive to successful moulding. It seemed to him that this machine had the merit of going in the right direction for accomplishing that object; and he hoped the matter would be taken up by ironfounders generally. He proposed a vote of thanks to Mr. Bagshaw for his paper.

GAS FURNACES.

Plate 1.

Fig. 1. *Crucible Steel Furnace with Reversing Regenerators underground.*

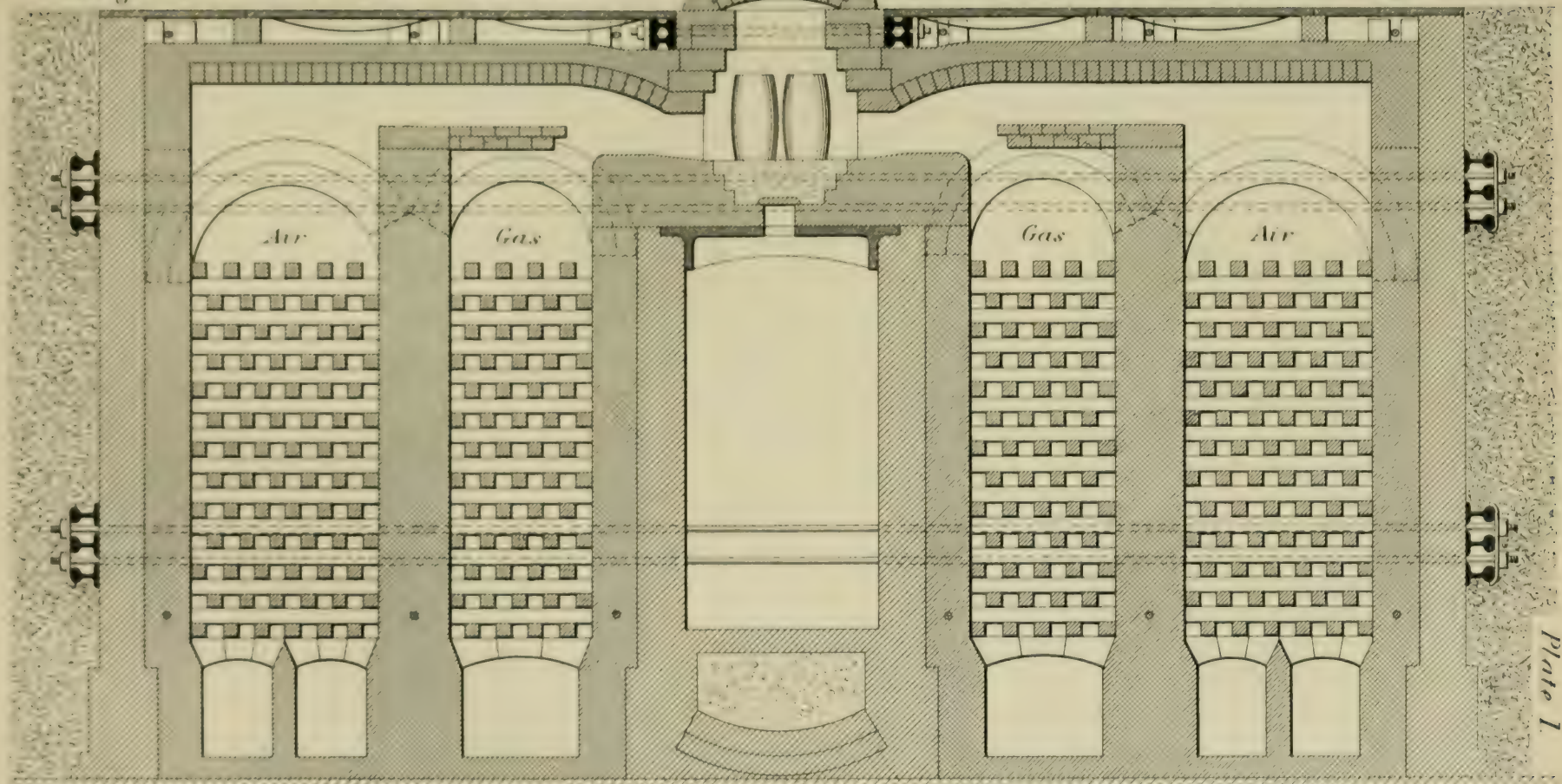


Plate 1.

(Mechanical Engineers 1891

Basic Steel Furnace with Reversing Regenerators above ground.

Fig. 2. *Sectional Plan.*

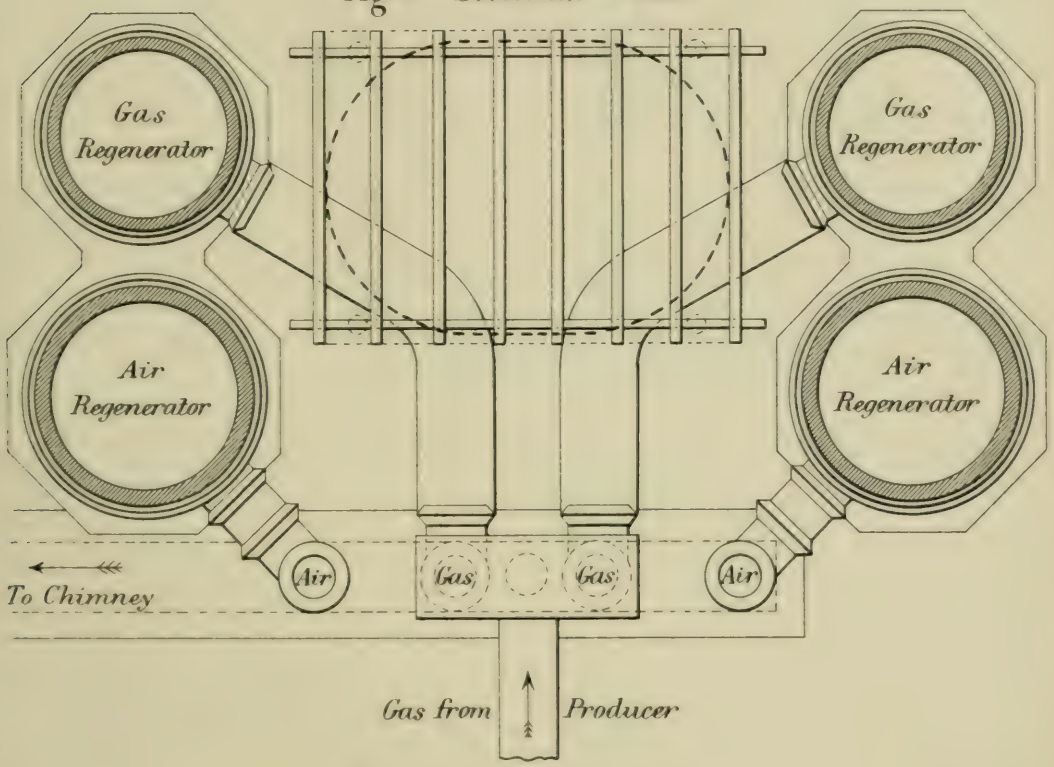
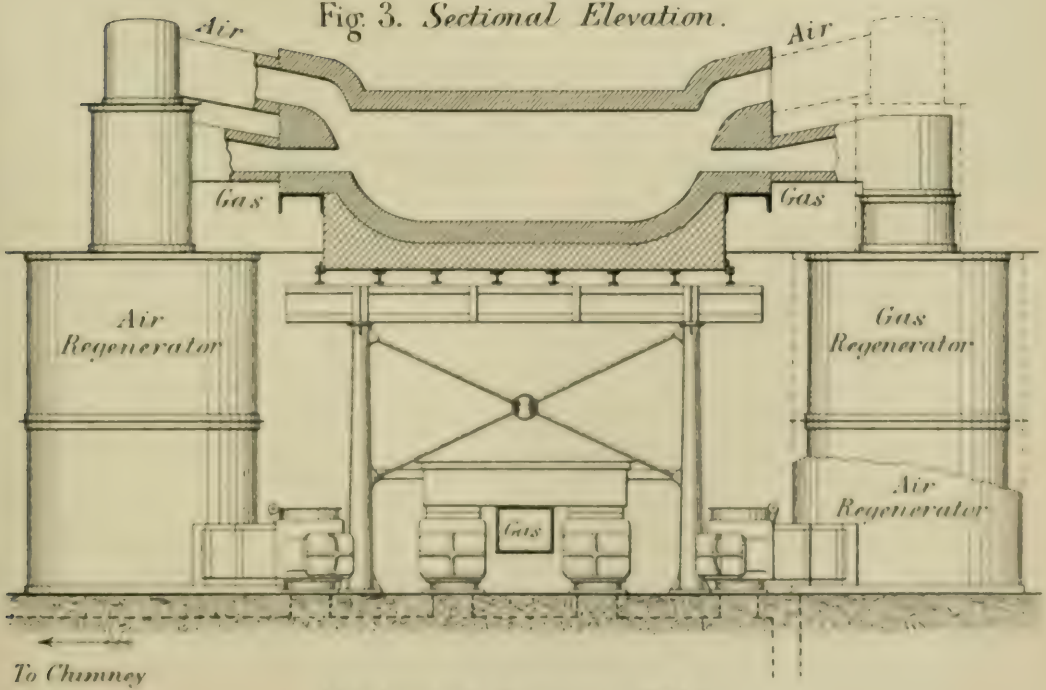


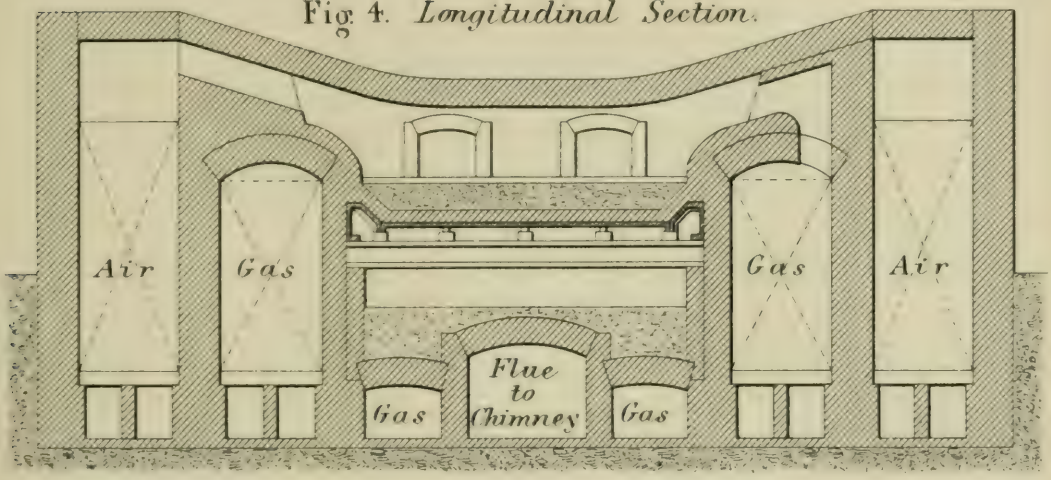
Fig. 3. *Sectional Elevation.*



(Mechanical Engineers 1891)

Heating Furnace with Regenerators above ground.

Fig. 4. *Longitudinal Section.*



Foundry Core and Mould Stove, Non-Regenerative.

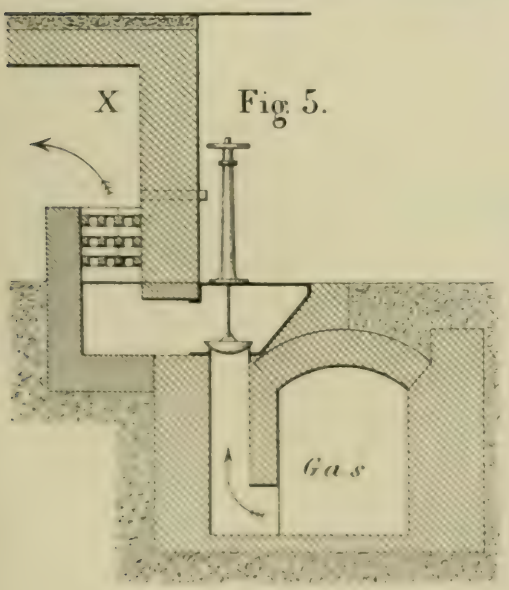


Fig. 5.

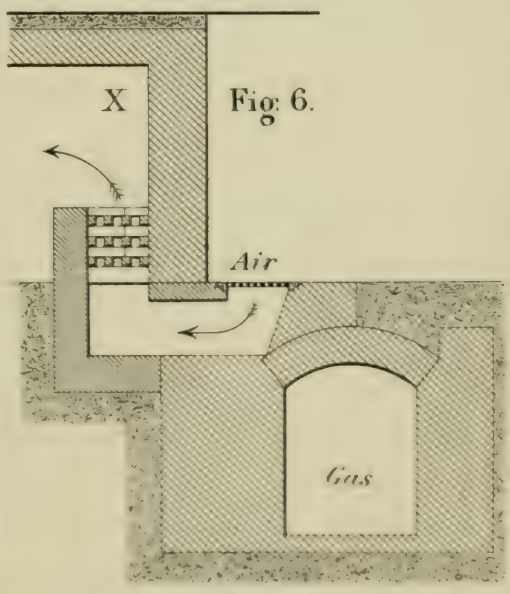
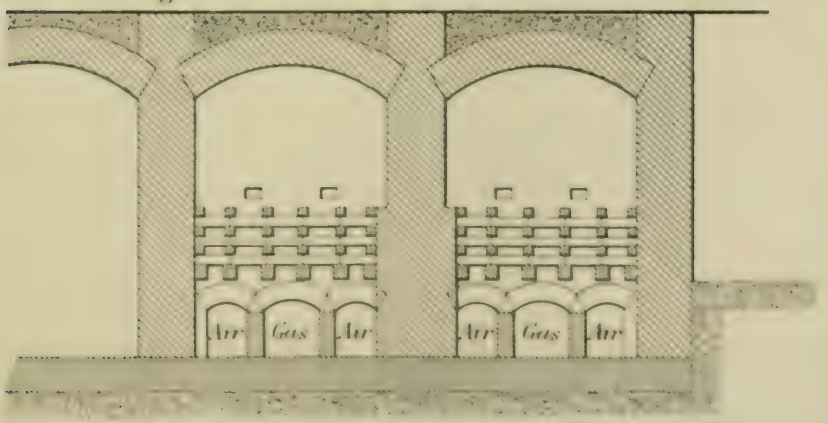


Fig. 6.

Fig. 7. *Transverse Section at X.*



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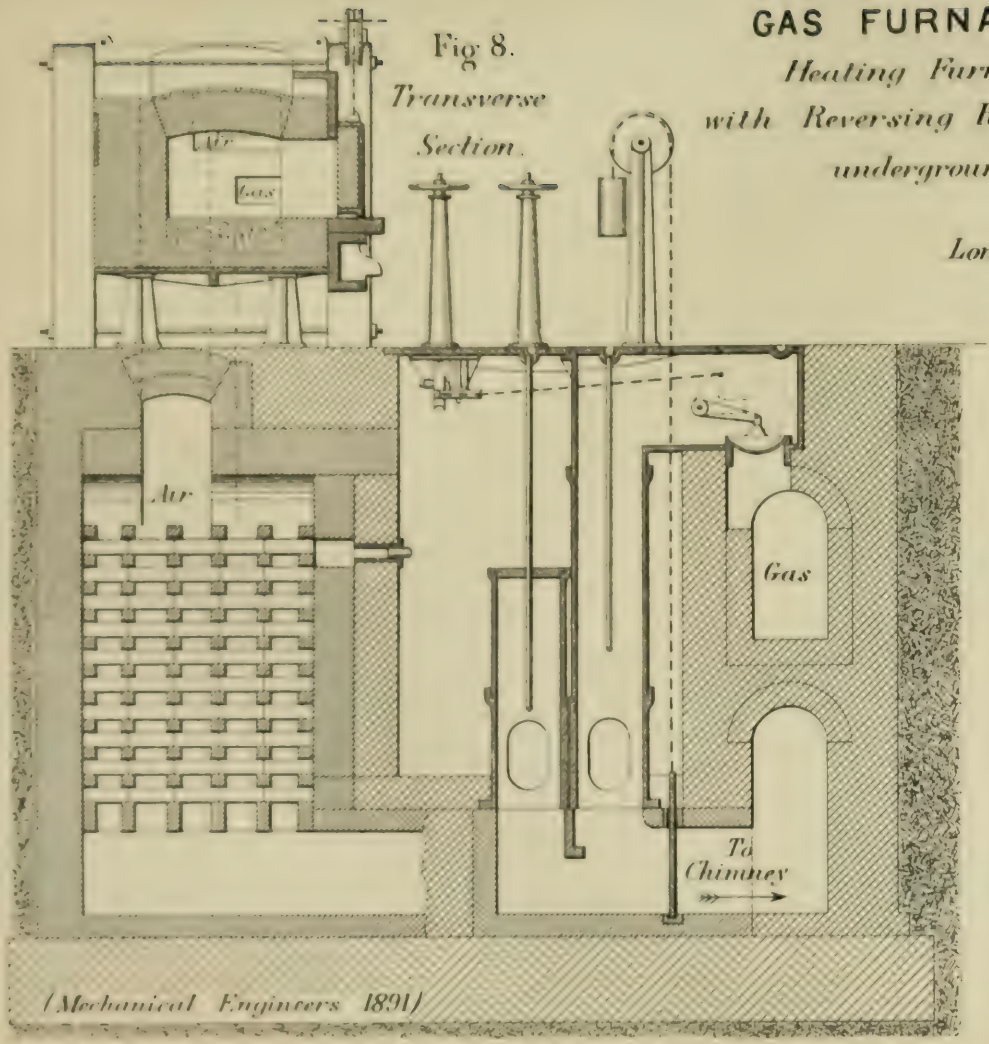
GAS FURNACES.

Heating Furnace with Reversing Regenerators underground.

Fig 8. *Transverse Section.*

Fig: 9. *Longitudinal Section.*



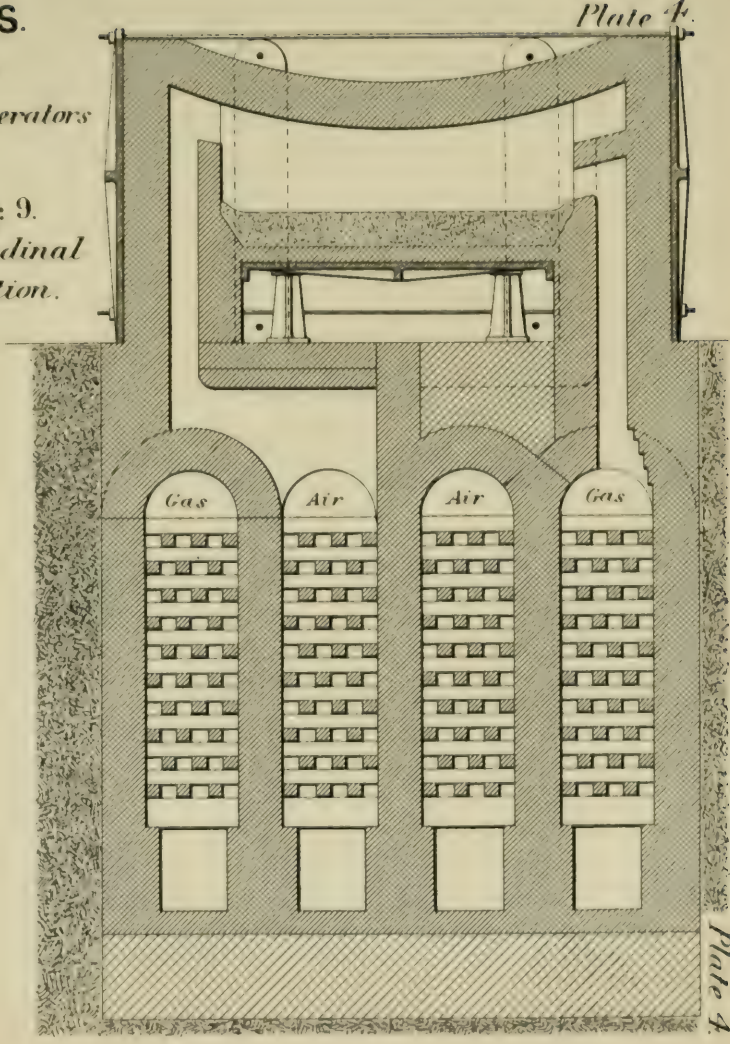


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Plate 4.

Plate 4.

Bar-heating Furnace with Reversing Regenerators.

Fig. 10. *Transverse Section.*

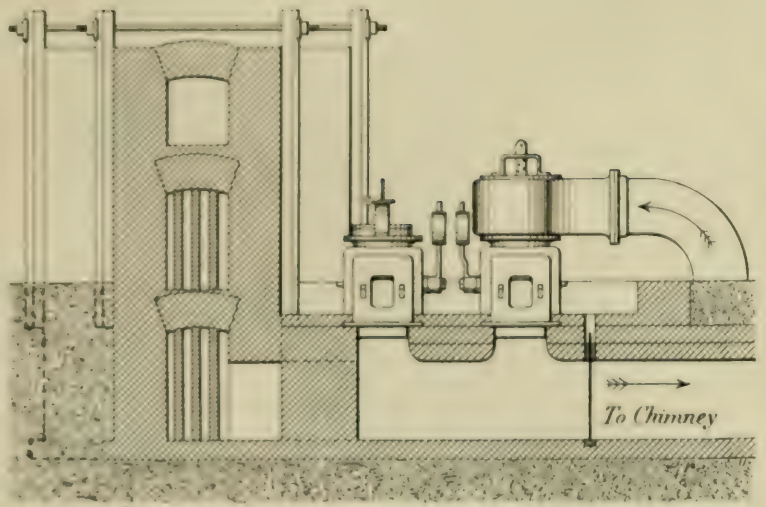

Fig. 11. *Longitudinal Section.*

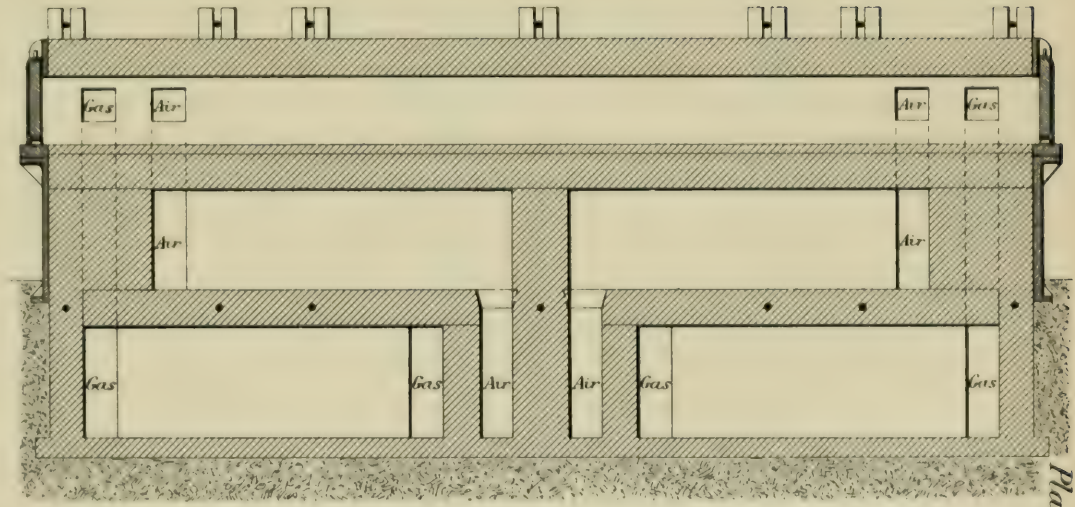

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Plate 5.

Reheating Furnace with Reversing Regenerators underground.

Fig. 12. *Sectional Plan.*

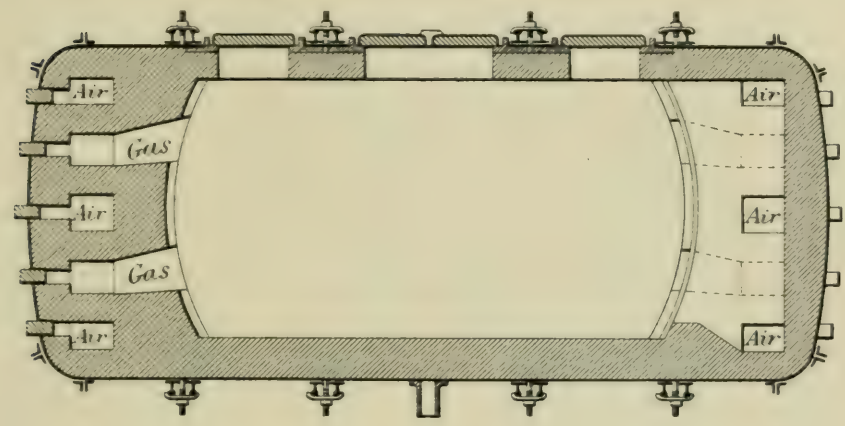
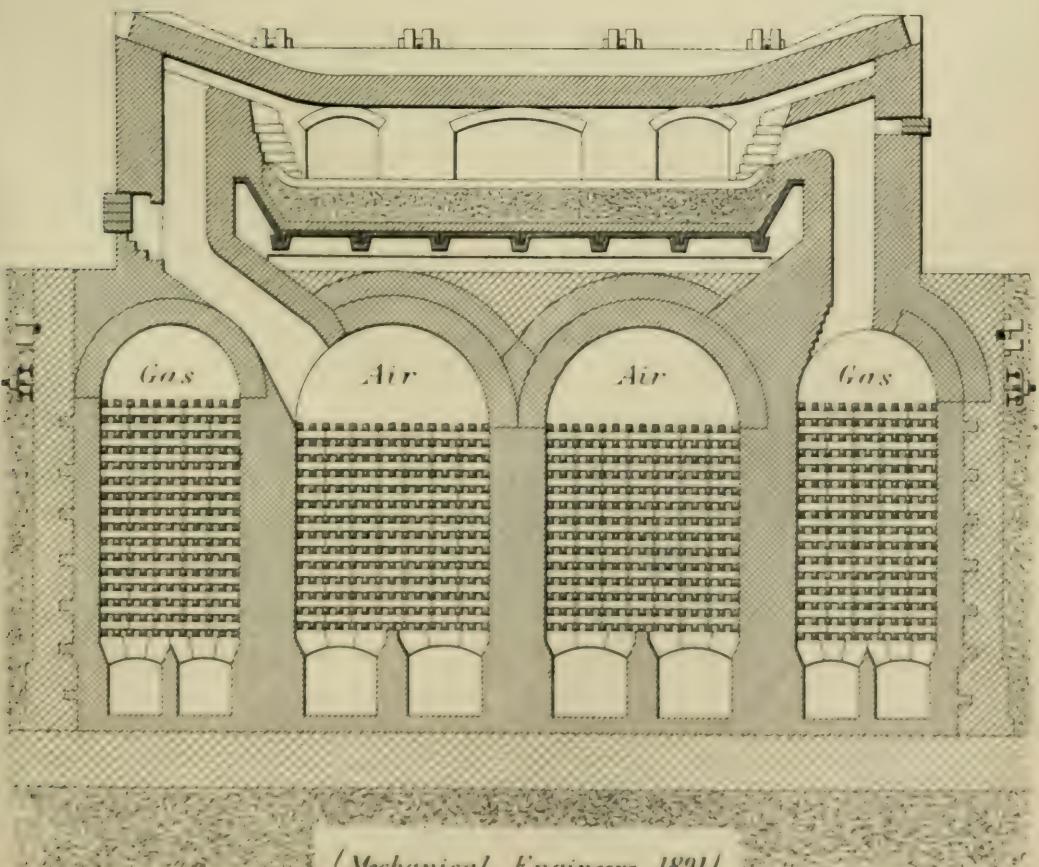


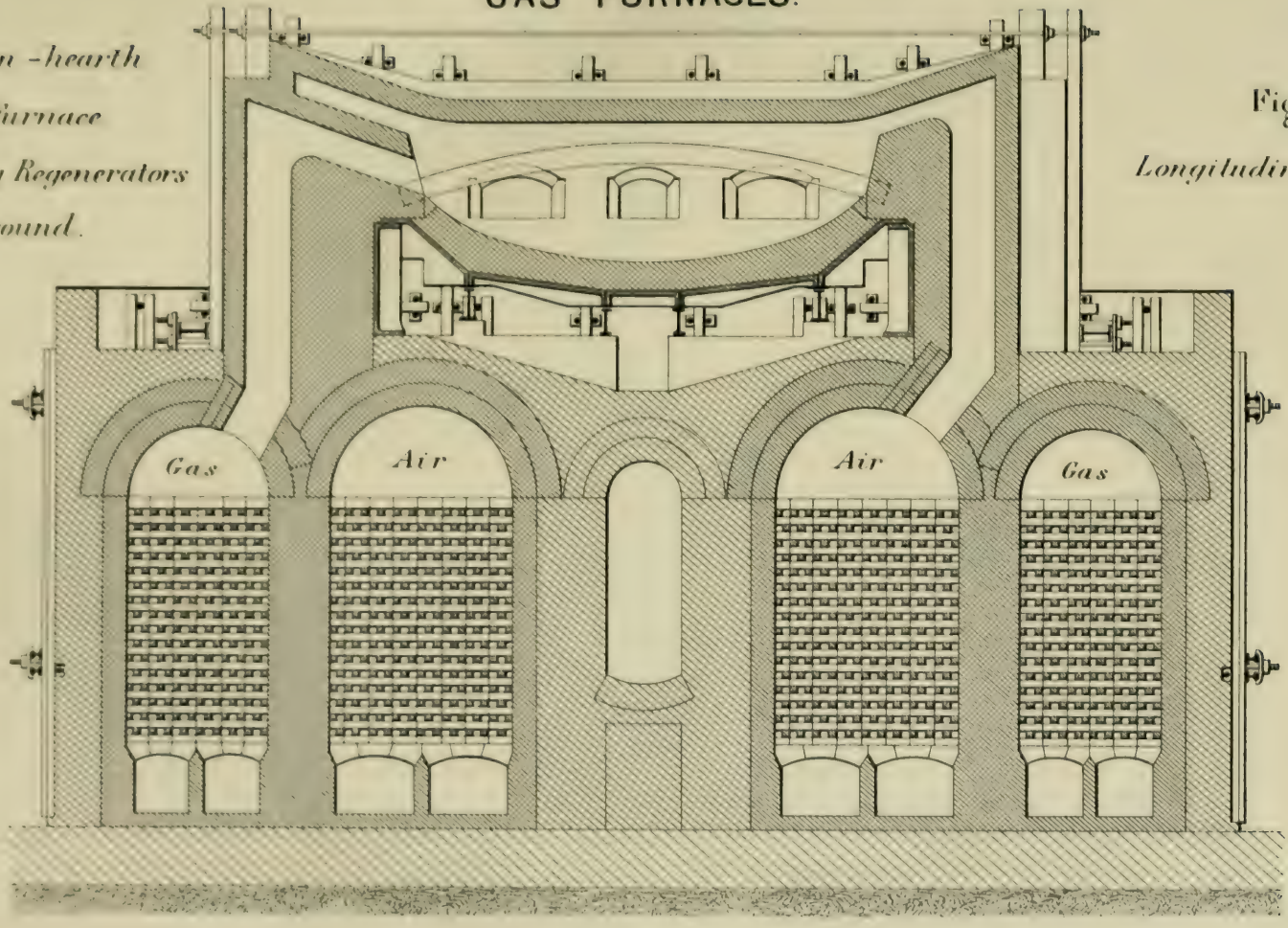
Fig. 13. *Vertical Section.*



Basic Open-hearth Steel Furnace with Reversing Regenerators underground.

Fig. 14.

Longitudinal Section.



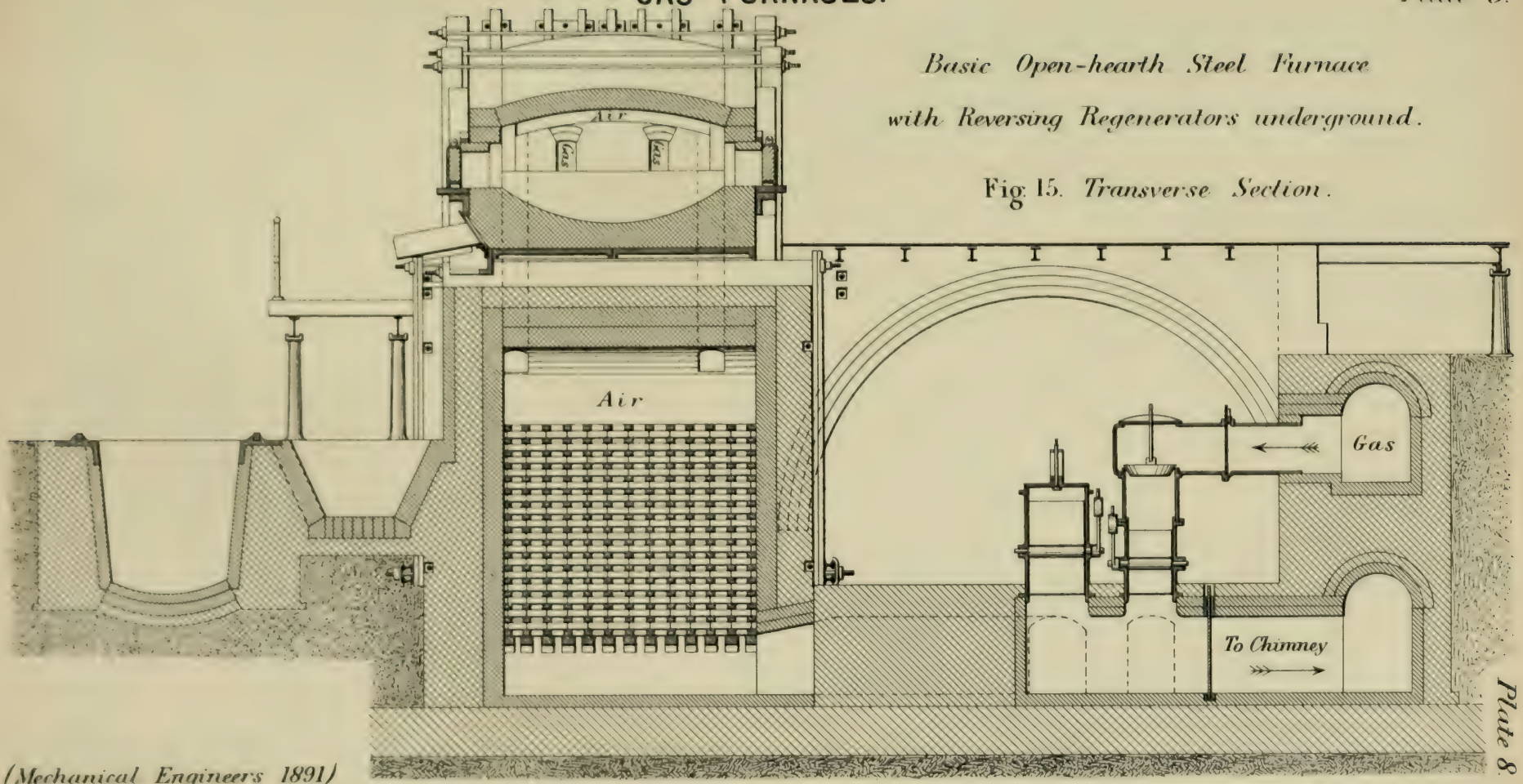
Mechanical Engineers 1891

Plate 7.

Basic Open-hearth Steel Furnace

with Reversing Regenerators underground.

Fig 15. *Transverse Section.*



(Mechanical Engineers 1891)

Plate 8.

Tire Furnace with Reversing Regenerators for Air only.

Fig. 16. *Longitudinal Section.*

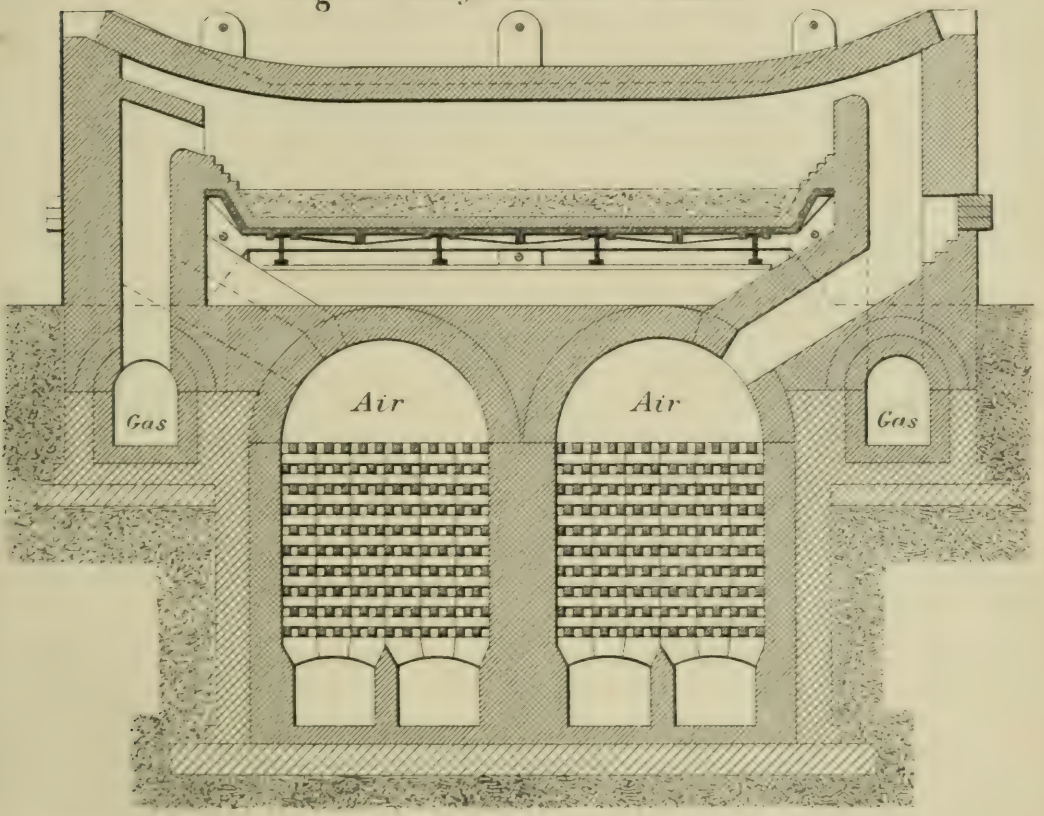
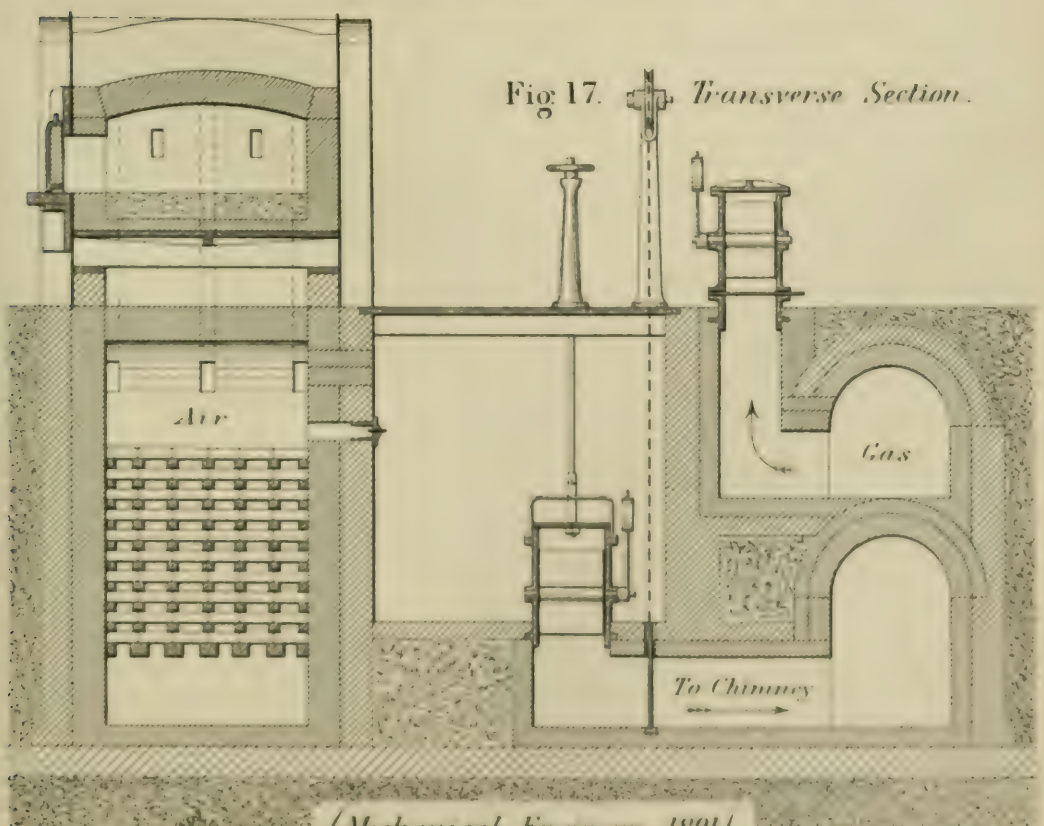


Fig. 17. *Transverse Section.*



Intermittent Glass Tank-Furnace with Reversing Regenerators underground.

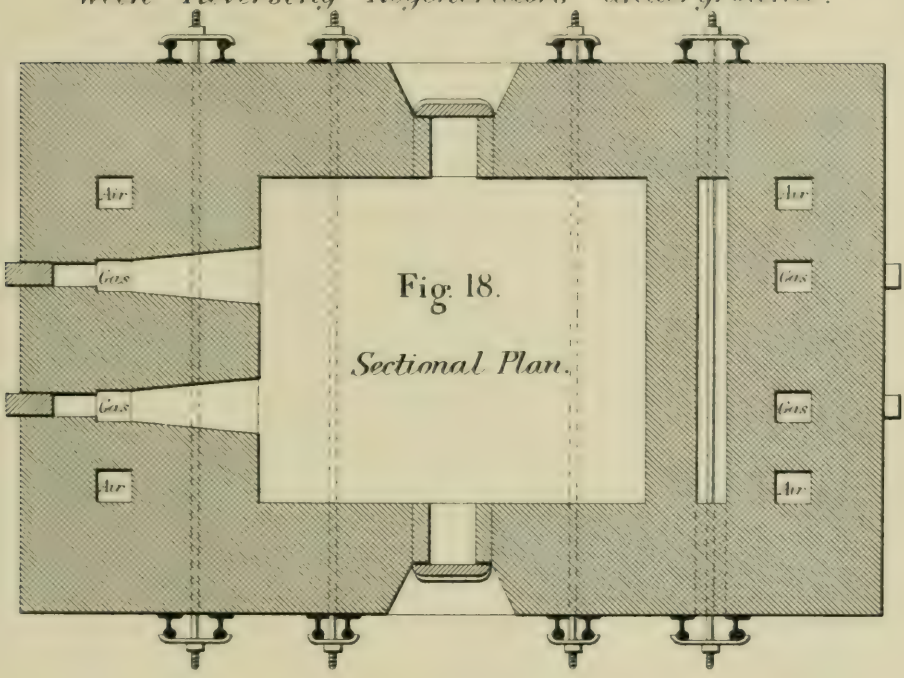
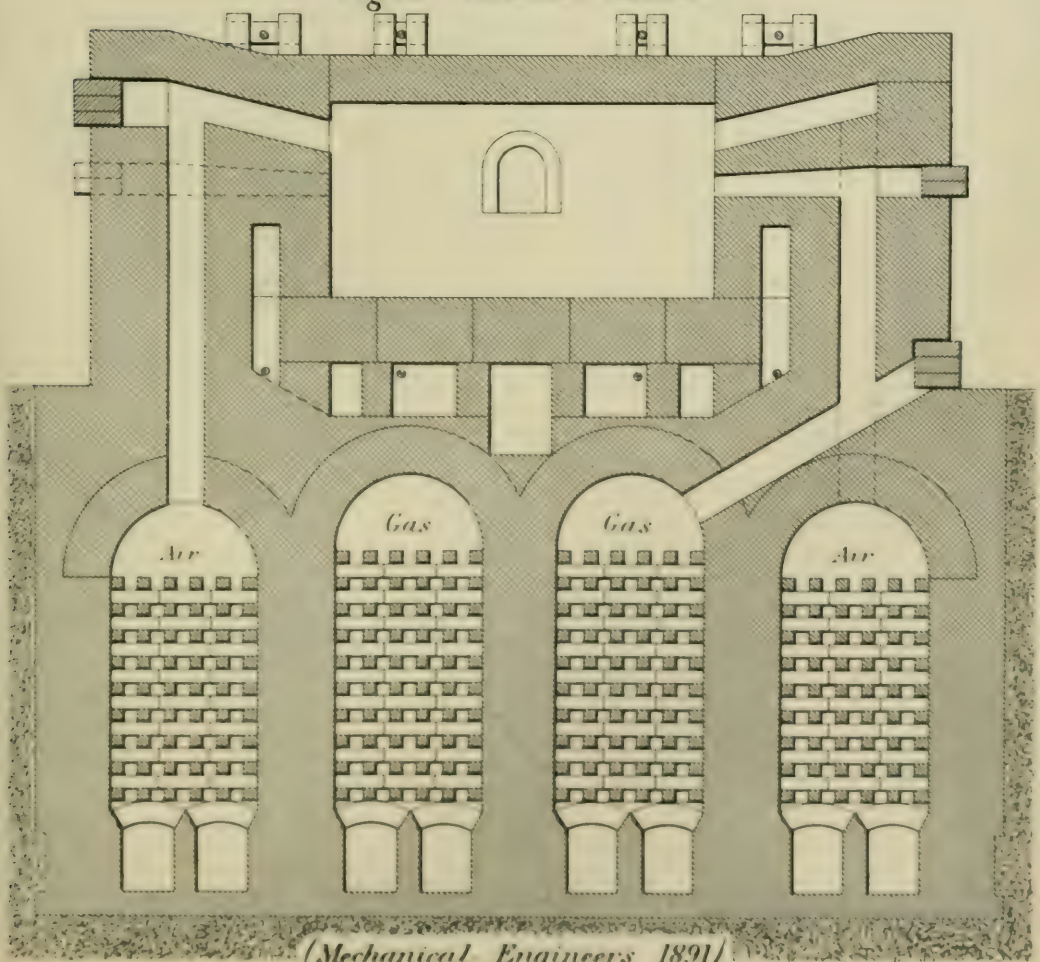


Fig. 18.

Sectional Plan.

Fig. 19. *Vertical Section.*



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GAS FURNACES.

Basic Open-hearth Steel Furnace with Reversing Regenerators overhead.

Fig. 20. *Longitudinal Section.*

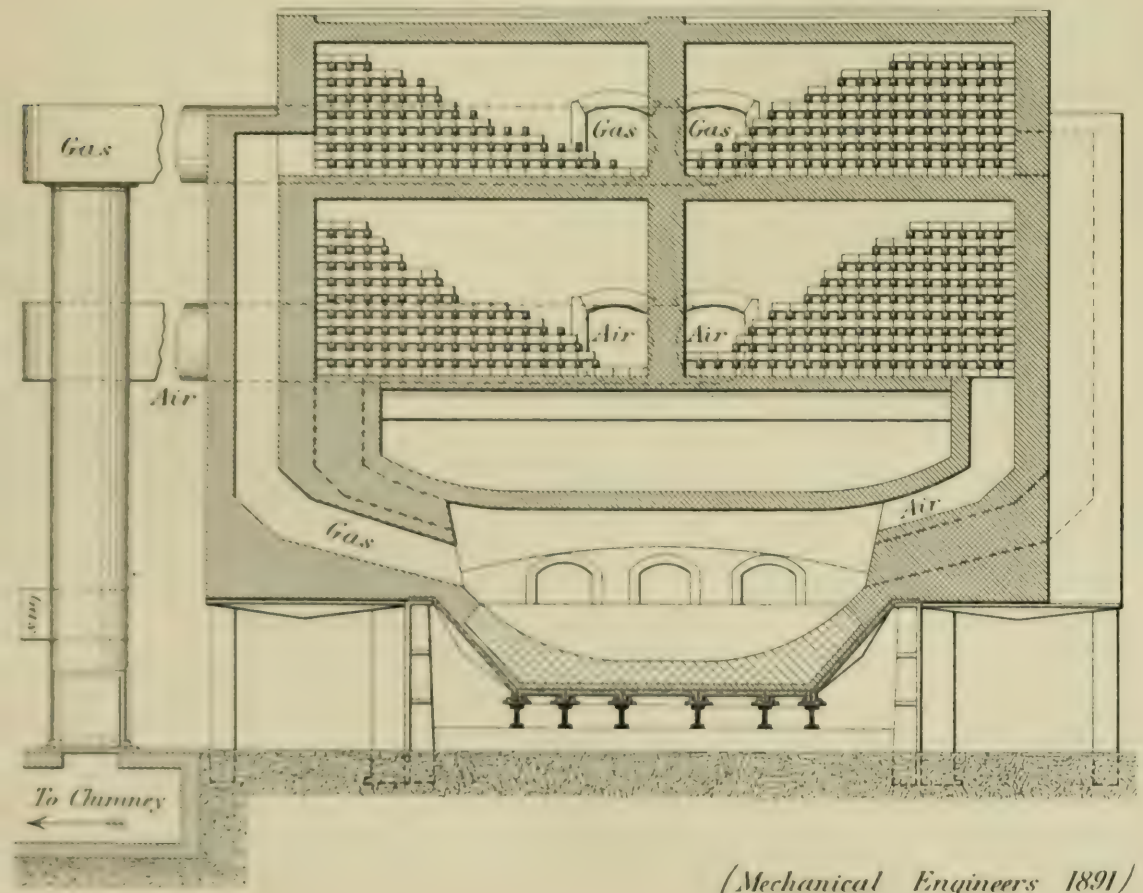


Fig. 21. *Transverse Section.*

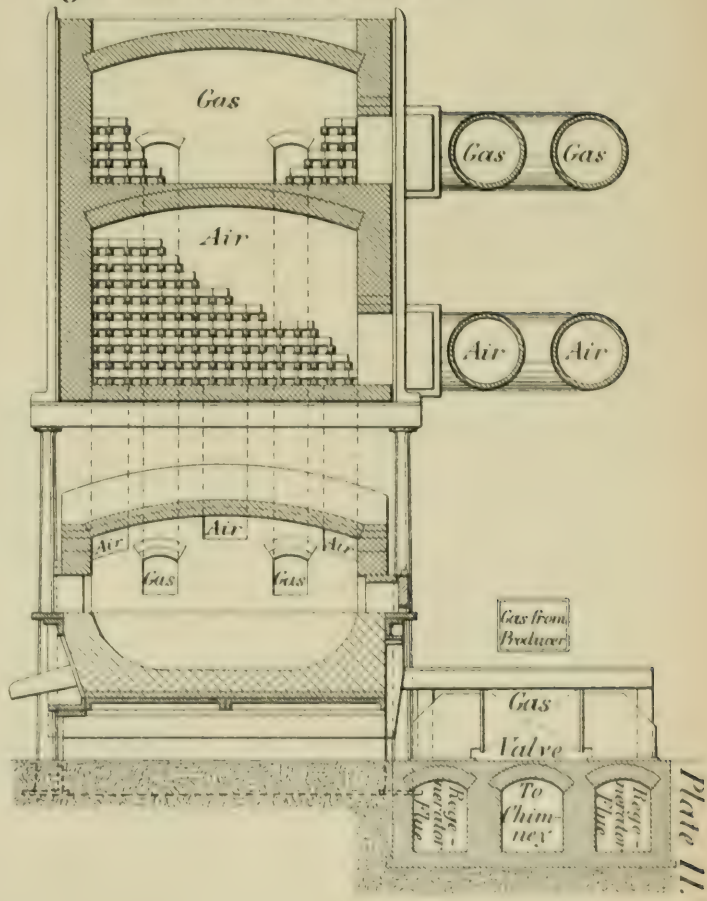


Plate II.

(Mechanical Engineers 1891)

Close-Annealing Furnace, with Continuous Air-Regeneration.

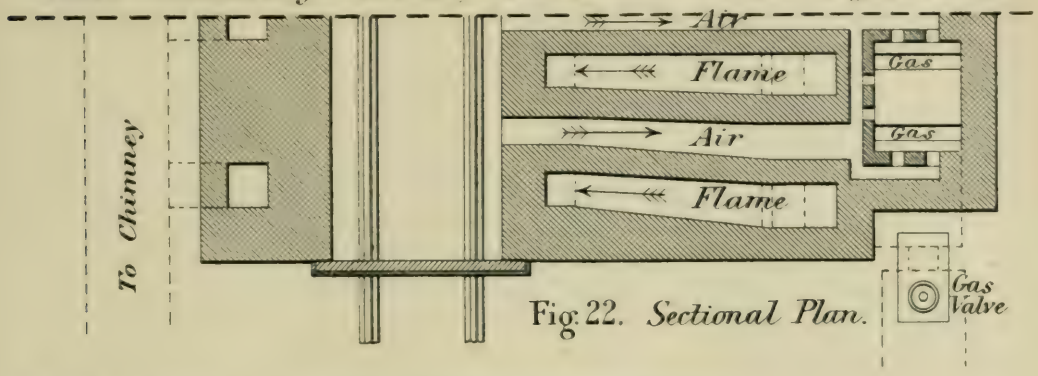
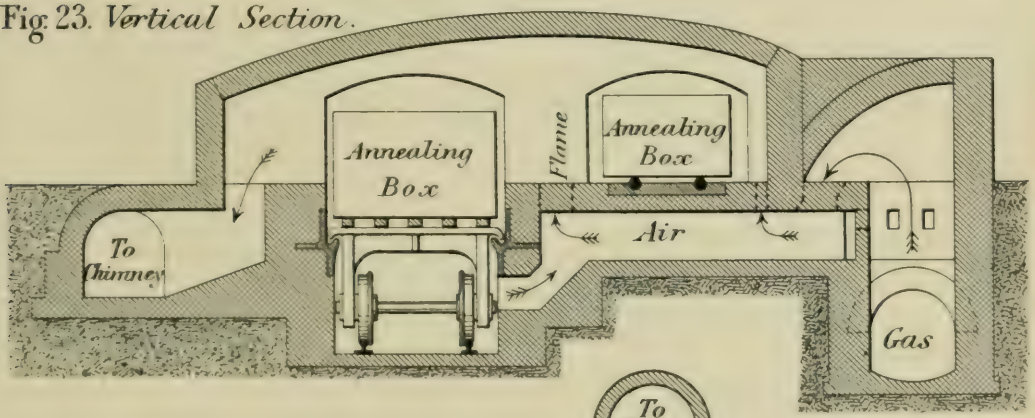


Fig. 22. *Sectional Plan.*

Fig. 23. *Vertical Section.*



Annealing Oven, with Continuous Air-Regeneration.

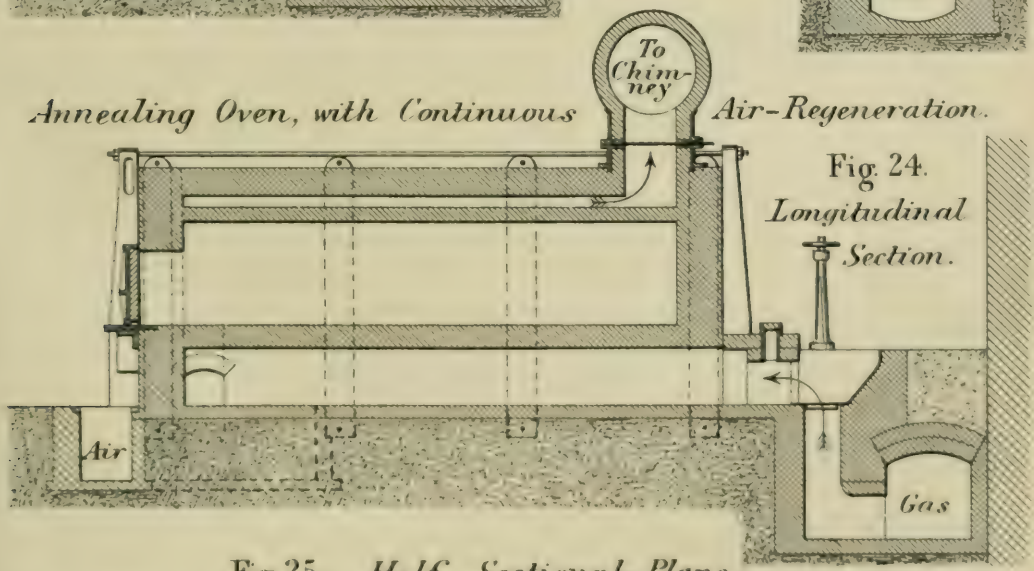
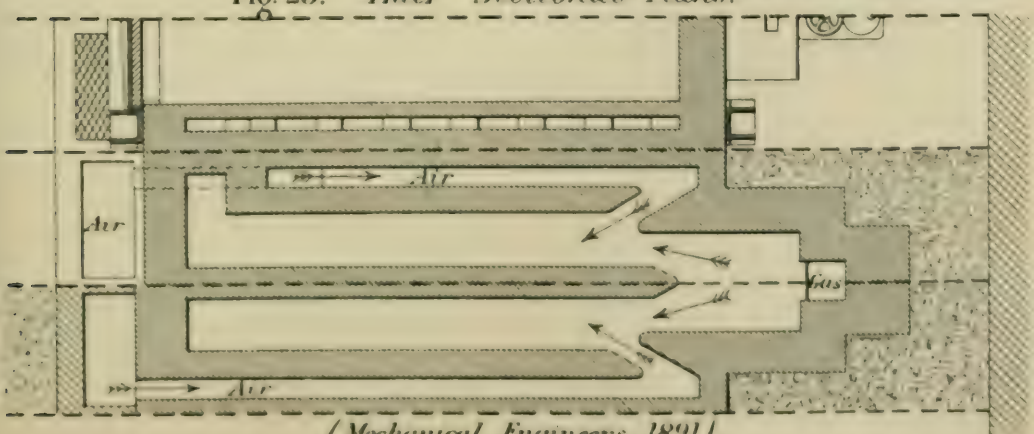


Fig. 24. *Longitudinal Section.*

Fig. 25. *Half Sectional Plans.*



(Mechanical Engineer 1891)

Annealing Oven with Continuous Air Regeneration.

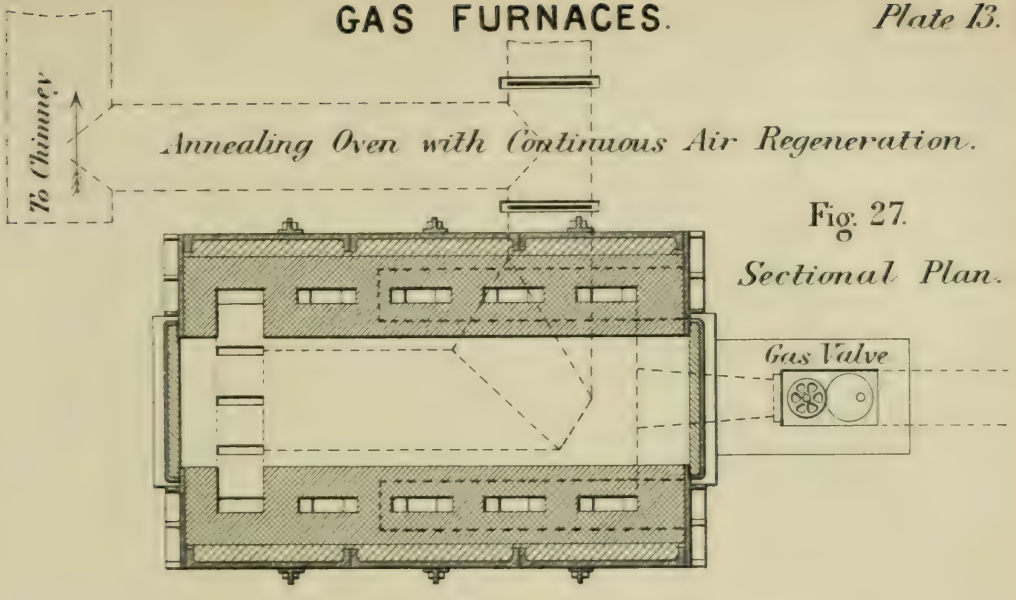


Fig. 27.
Sectional Plan.

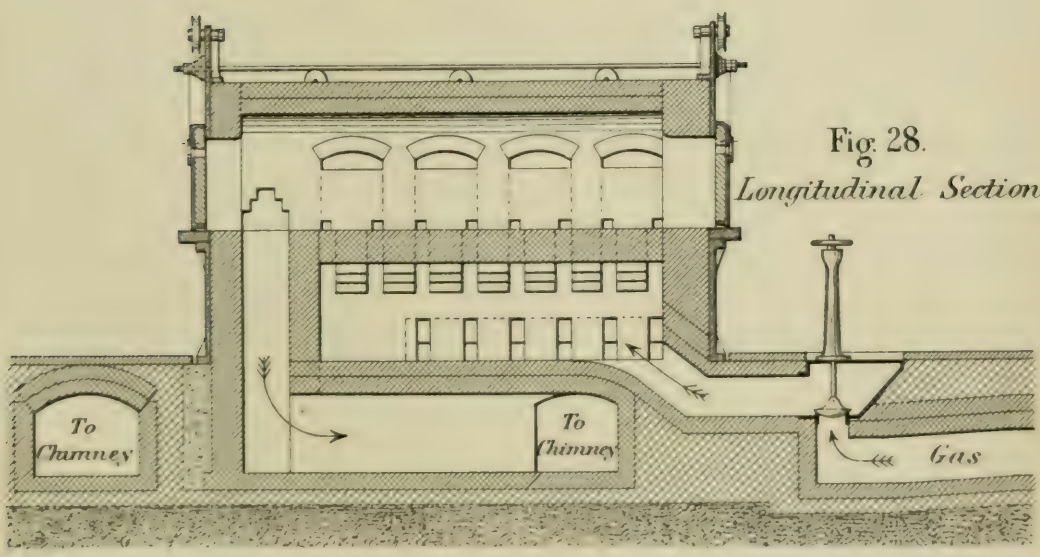


Fig. 28.
Longitudinal Section.

Fig. 26. Transverse Section of Fig. 24.

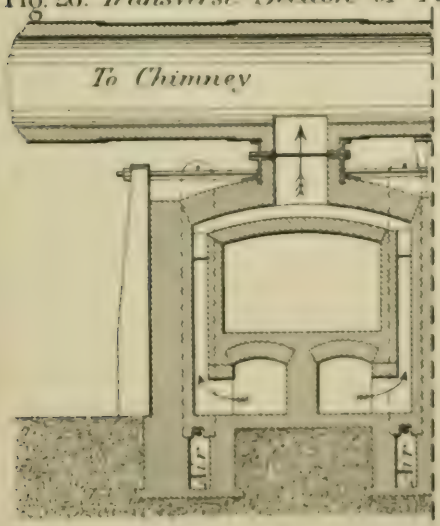
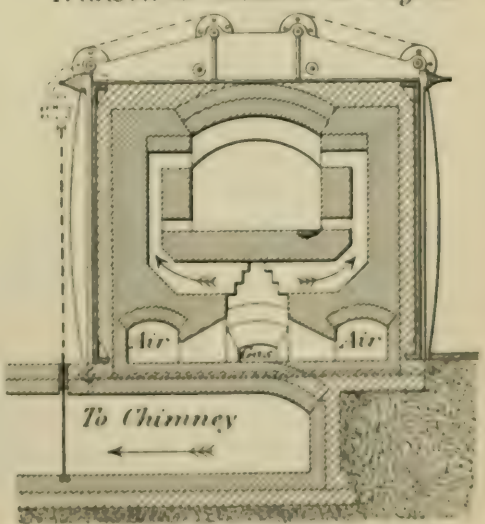


Fig. 29.
Transverse Section of Fig. 28.



(Mechanical Engineers 1891)

Plate-heating Furnace. Non-Regenerative.

Fig. 30. *Sectional Plan.*

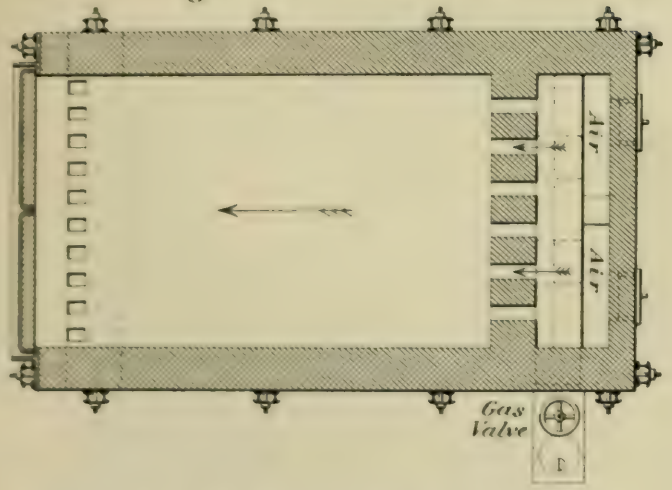
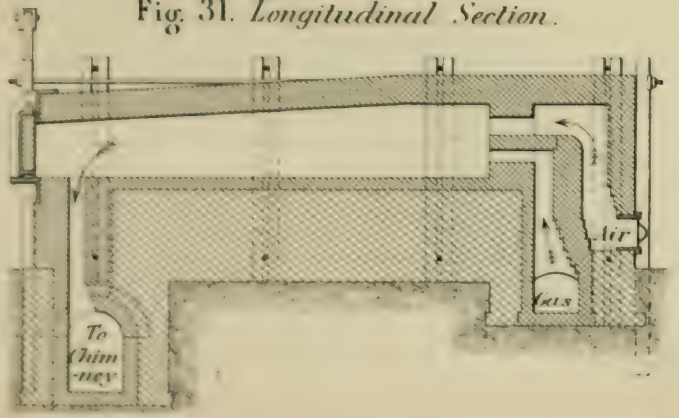
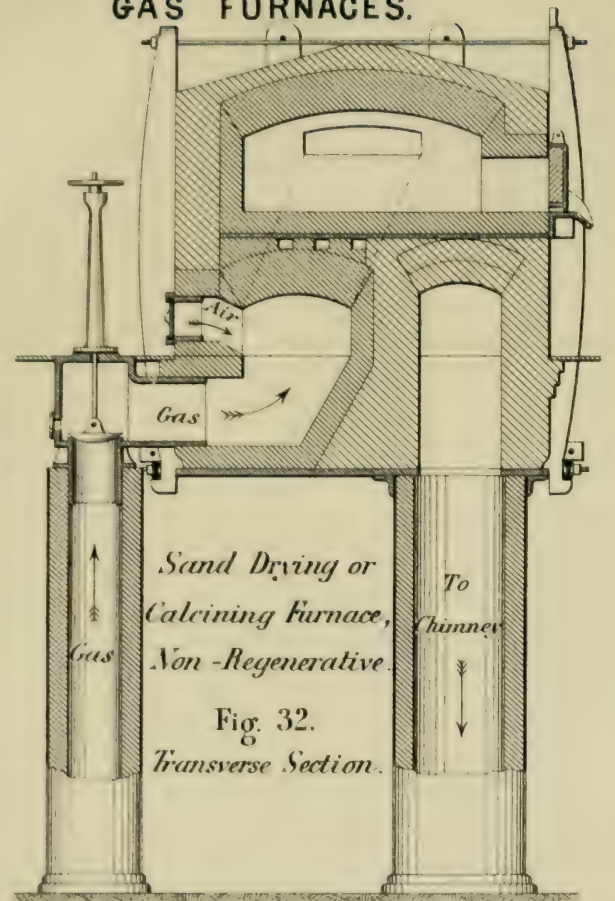


Fig. 31. *Longitudinal Section.*

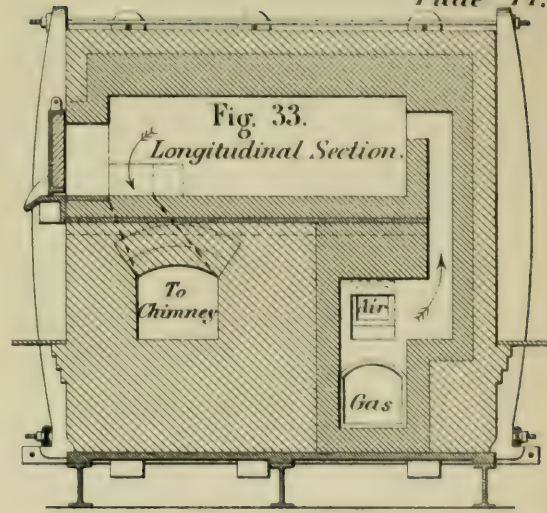




Sand Drying or Calcining Furnace, Non-Regenerative.

Fig. 32. *Transverse Section.*

Fig. 33. *Longitudinal Section.*



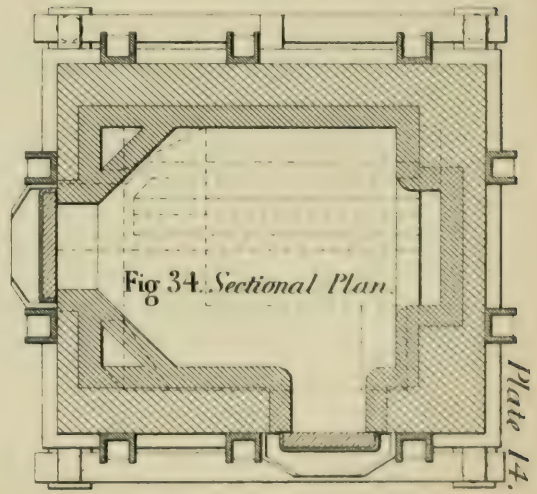


Fig. 34. *Sectional Plan.*

Plate 14.

Oil Boiler, Non-Regenerative.

Vertical Sections.

Fig. 35.

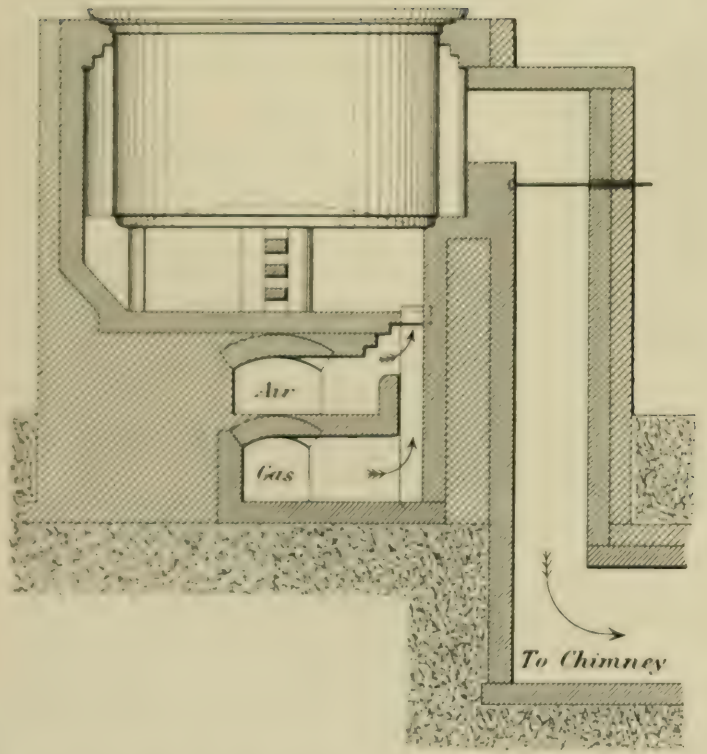


Fig. 36.

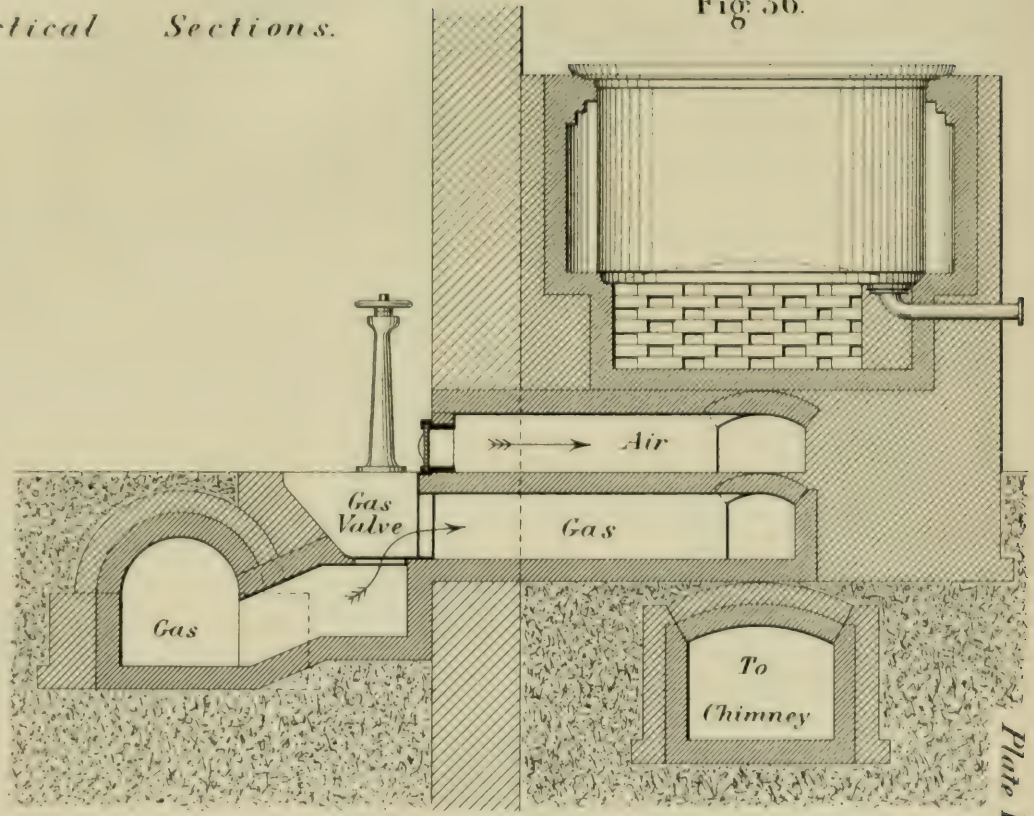


Plate 15.

(Mechanical Engineers 1891)

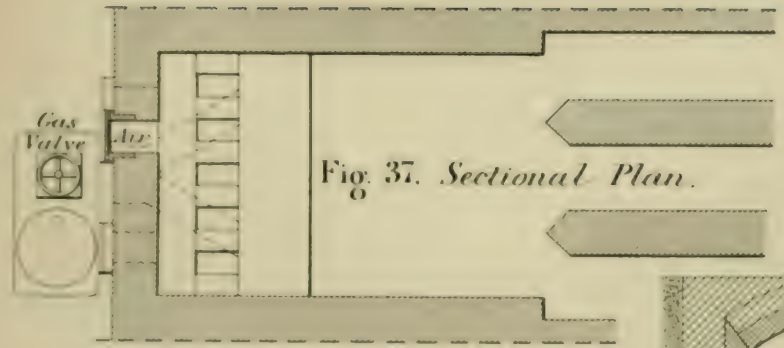


Fig. 37. *Sectional Plan.*

Slurry-drying Floor, Non-Regenerative.

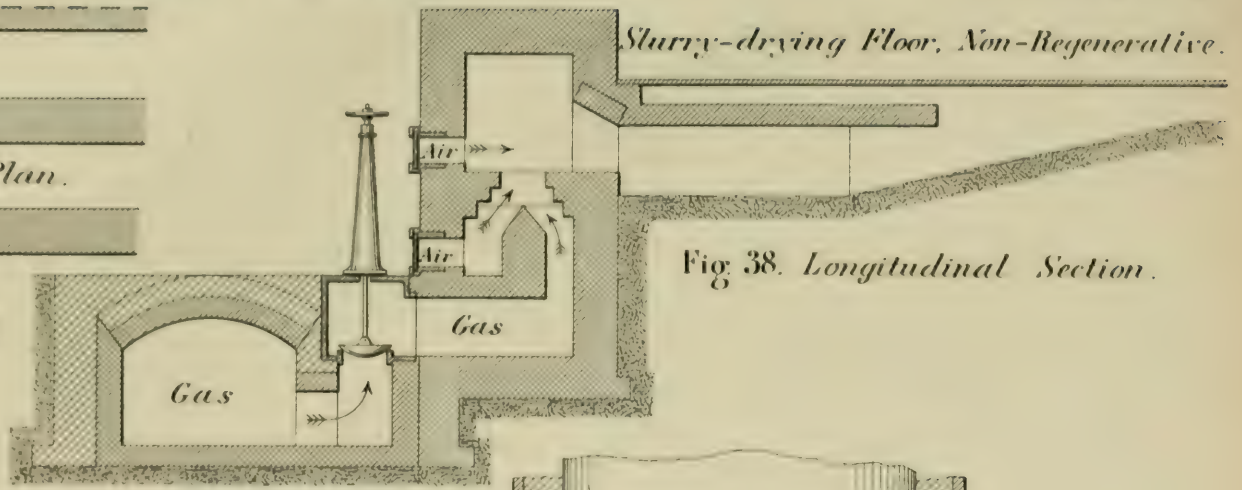
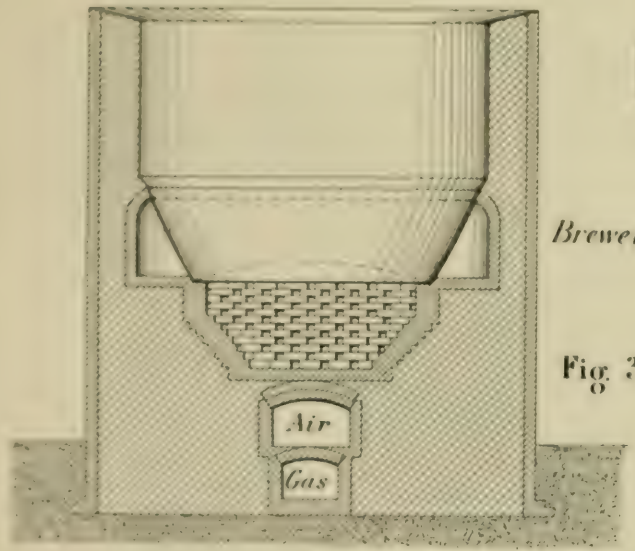


Fig. 38. *Longitudinal Section.*



Brewers' Copper, Non-Regenerative.

Vertical Sections.

Fig. 39.

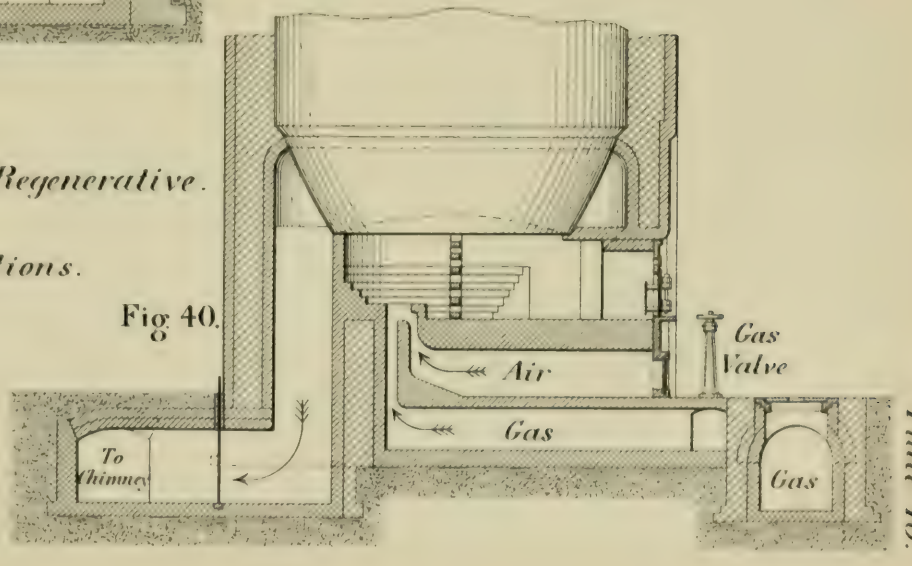


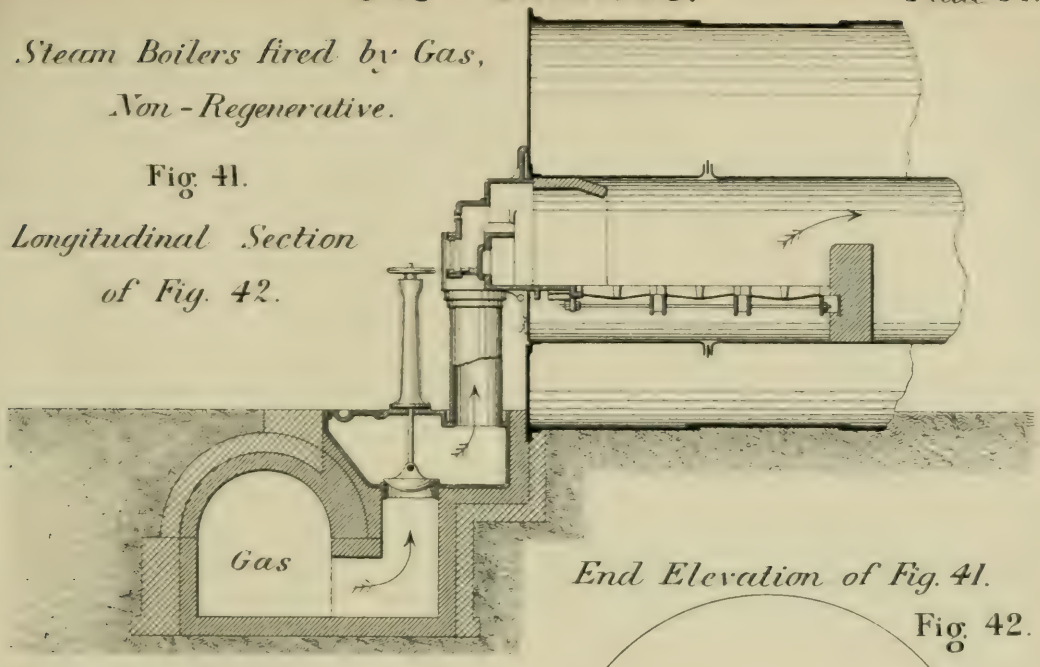
Fig. 40.

[Mechanical Engineers 1891]

Plate 16.

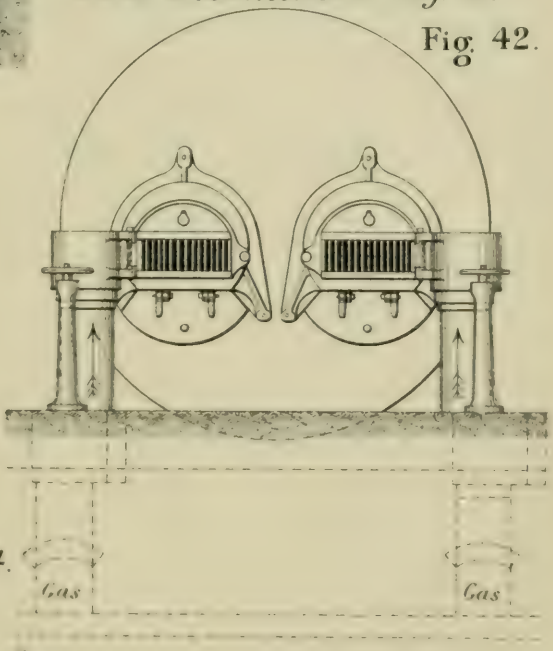
Steam Boilers fired by Gas,
Non-Regenerative.

Fig. 41.
Longitudinal Section of Fig. 42.



End Elevation of Fig. 41.

Fig. 42.



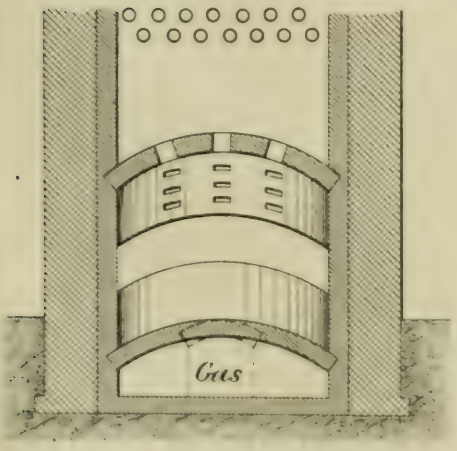
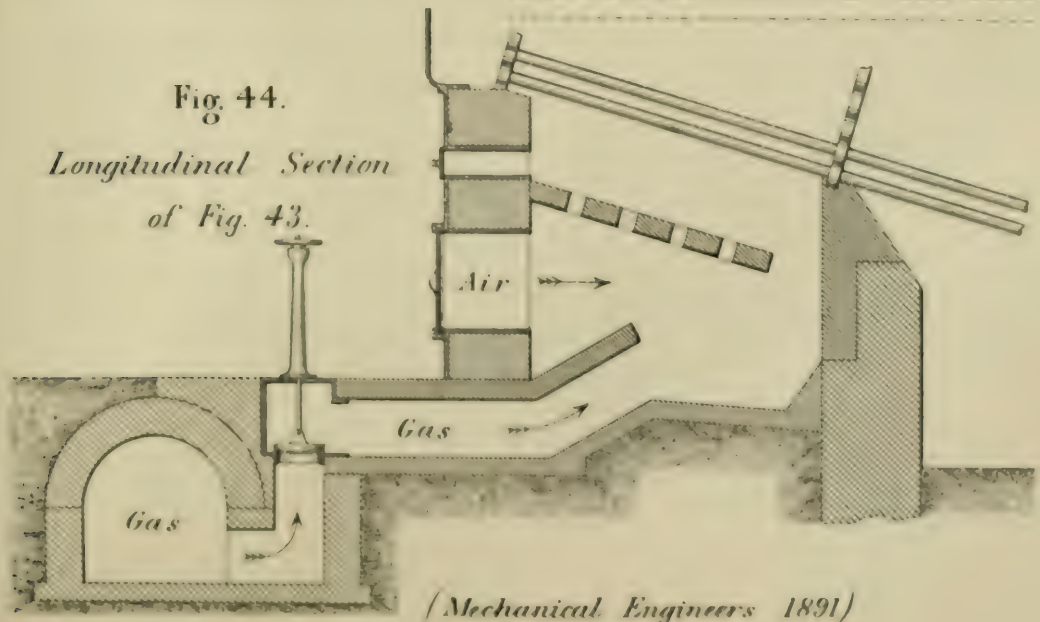


Fig. 43. *Transverse Section of Fig. 44.*

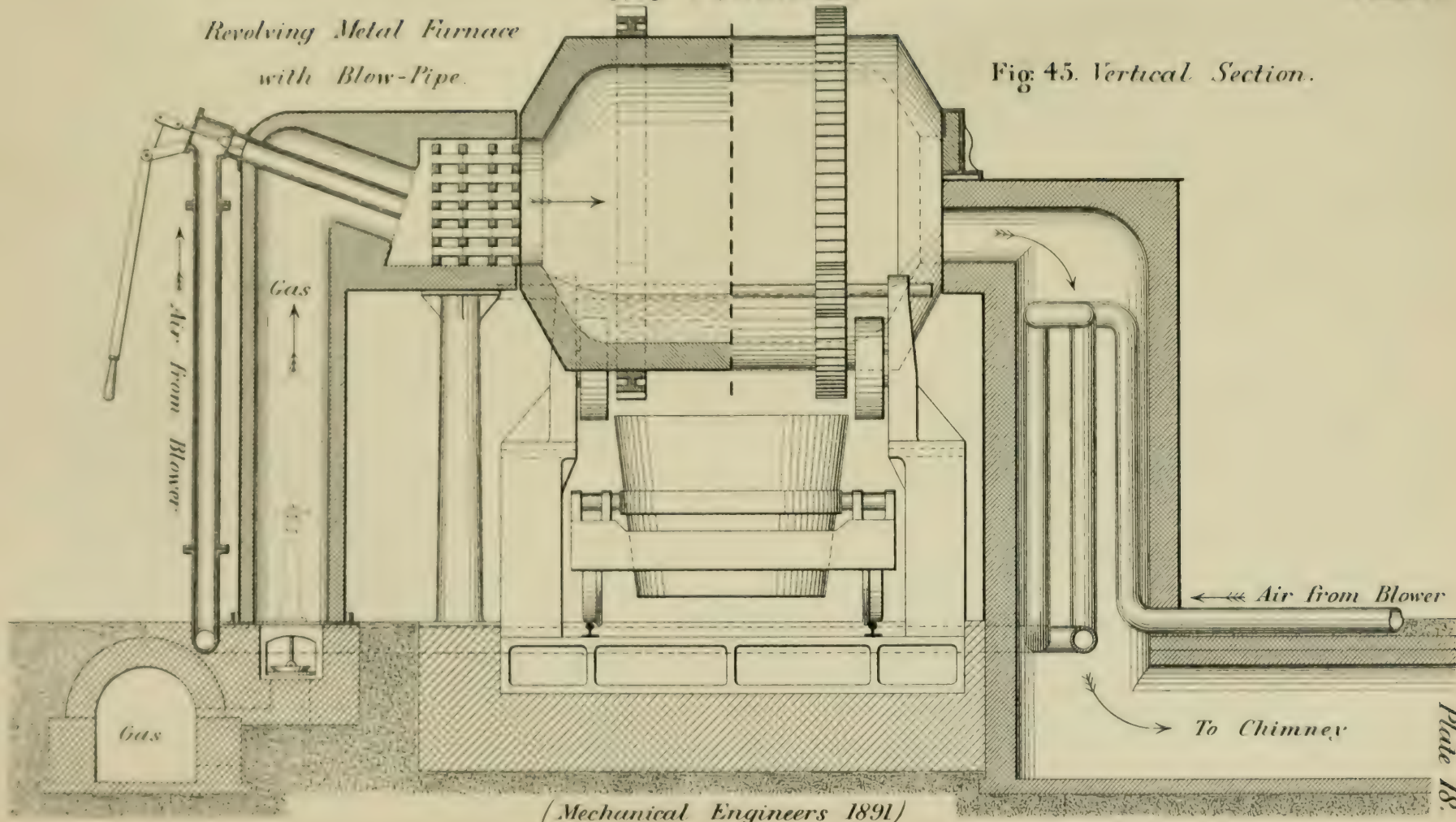
Fig. 44.
Longitudinal Section of Fig. 43.



(Mechanical Engineers 1891)

Revolving Metal Furnace with Blow-Pipe.

Fig. 45. *Vertical Section.*



(Mechanical Engineers 1891)

Plate 18.

GAS FURNACES.

Plate-Heating Furnace with Blow-Pipe.

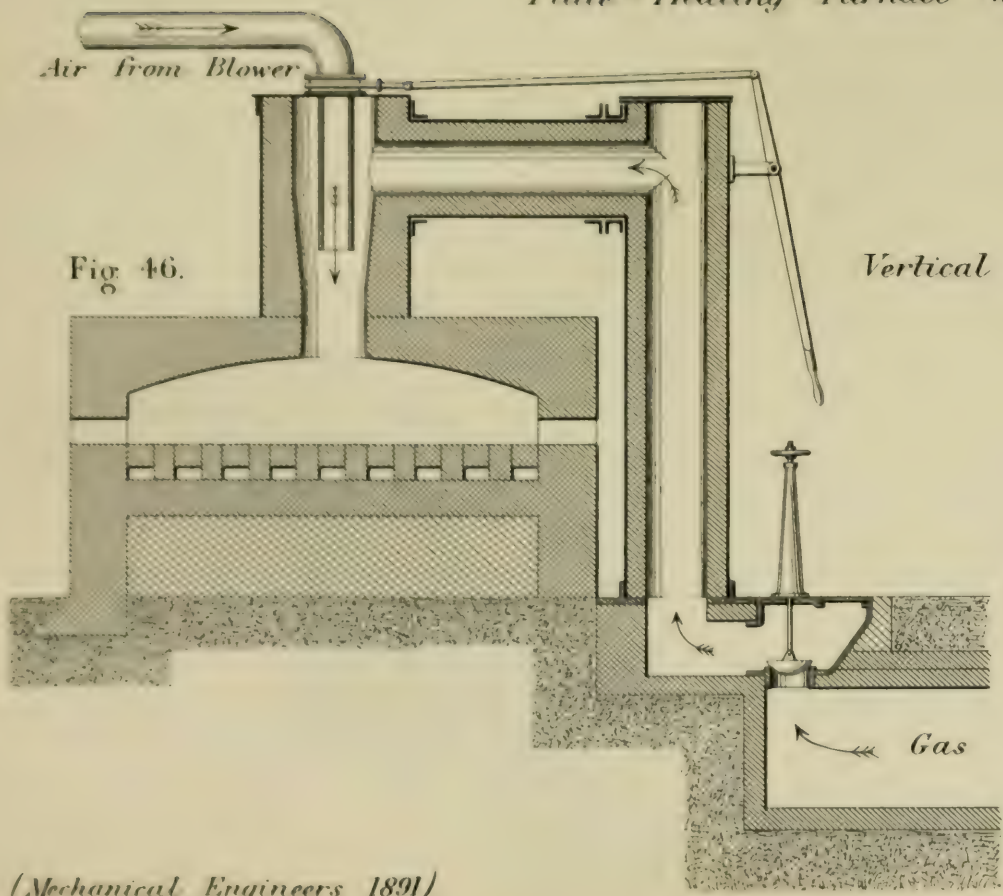


Fig. 46.

Vertical Sections.

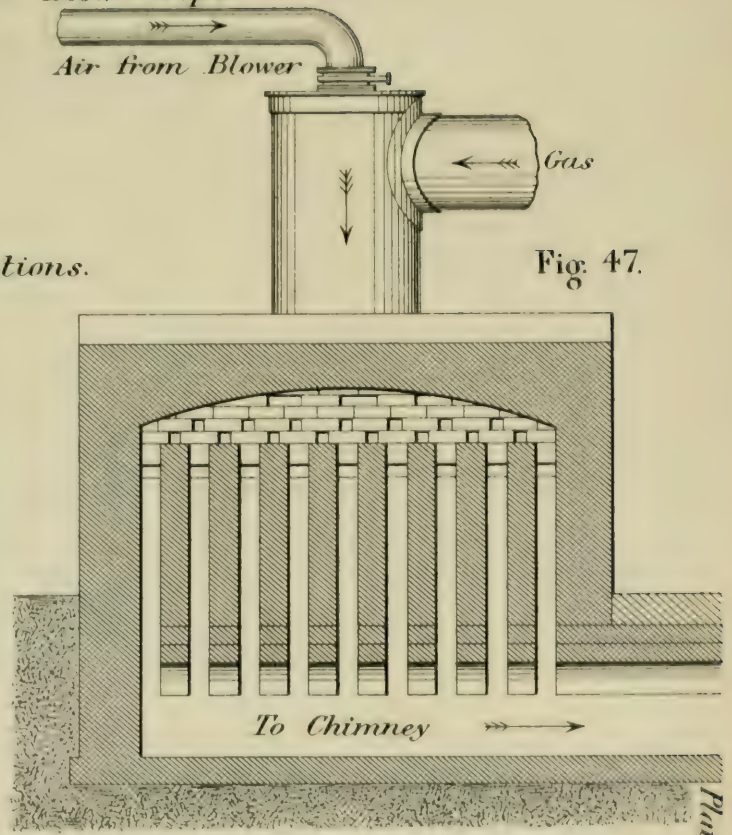


Fig. 47.

(Mechanical Engineers 1891)

Plate 19.

Crucible Silver-Melting Furnace with Blow-Pipe.

Fig. 48. *Plan.*

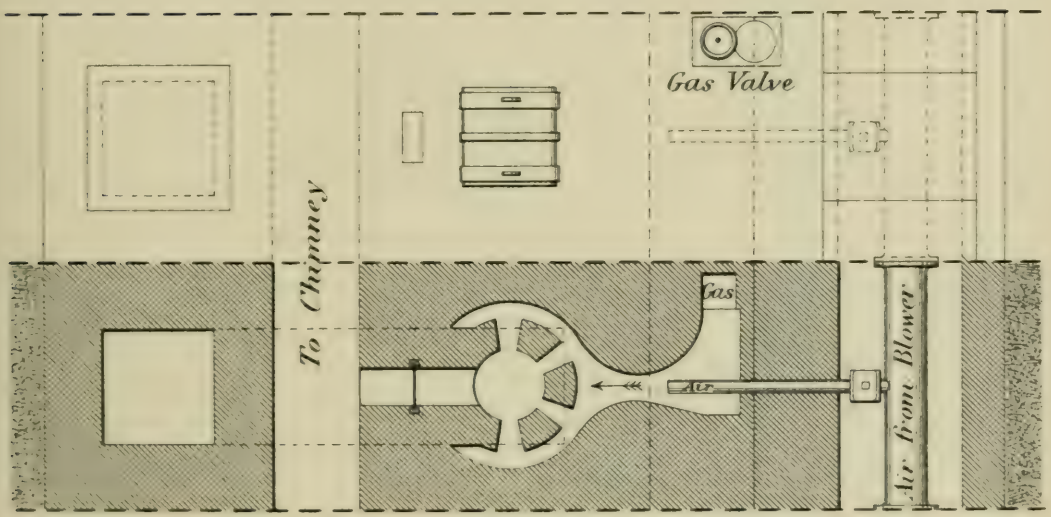
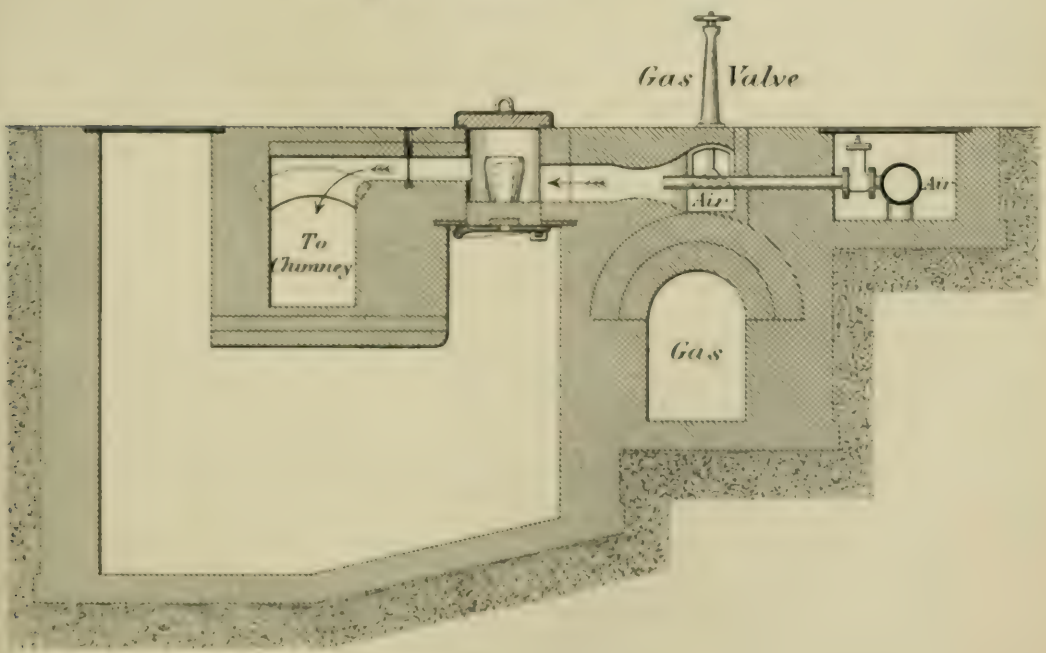


Fig. 49. *Vertical Section.*



(Mechanical Engineers 1891)

GAS FURNACES.

Steel Melting Furnace combined with Gas Producer, and having Air-Regenerator overhead.

Fig. 50. *Transverse Section.*

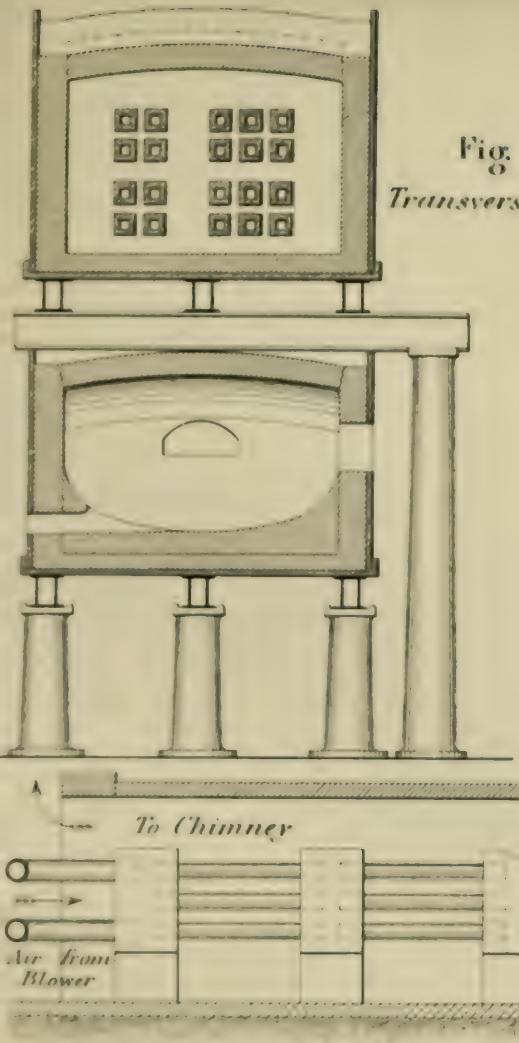
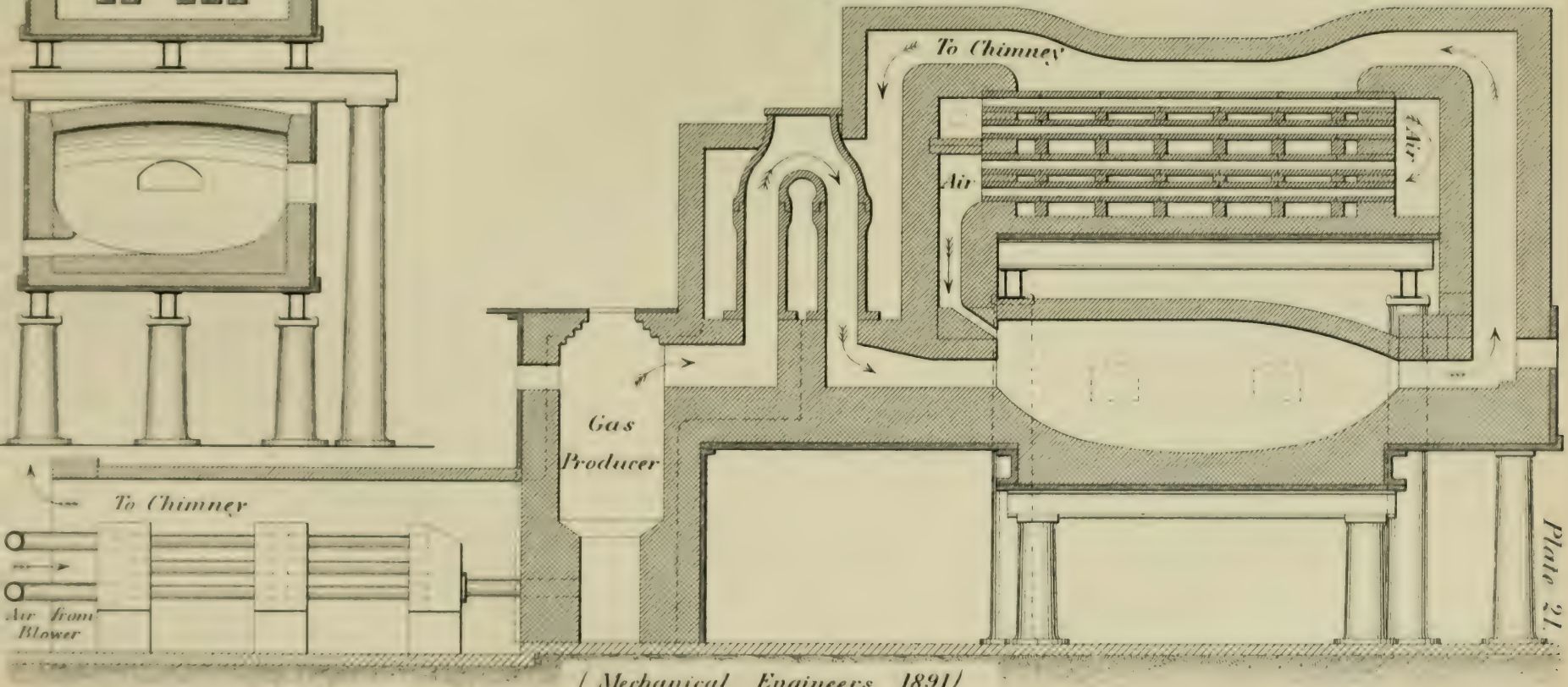


Fig. 51. *Longitudinal Section.*



(Mechanical Engineers 1891)

GAS FURNACES.

New Reversing Regenerative Furnace.

Fig. 52. *Ordinary Gas Producer. Vertical Section.*

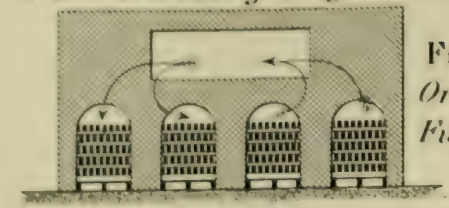


Fig. 53. *Original Furnace.*

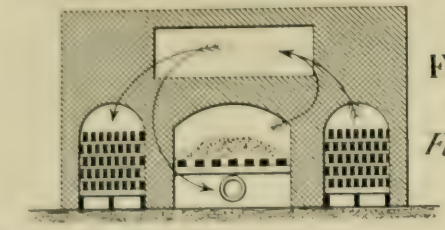


Fig. 54. *New Furnace.*

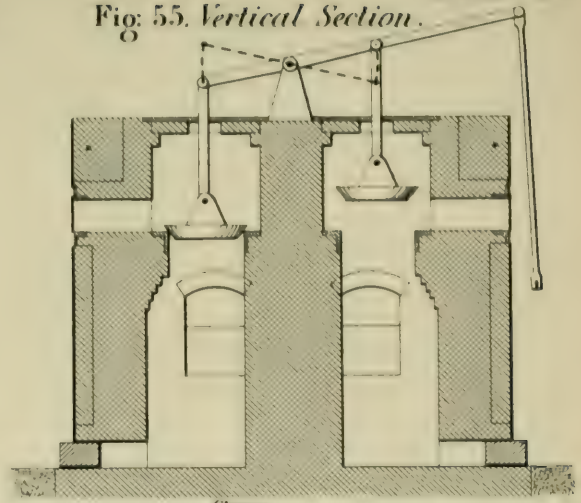
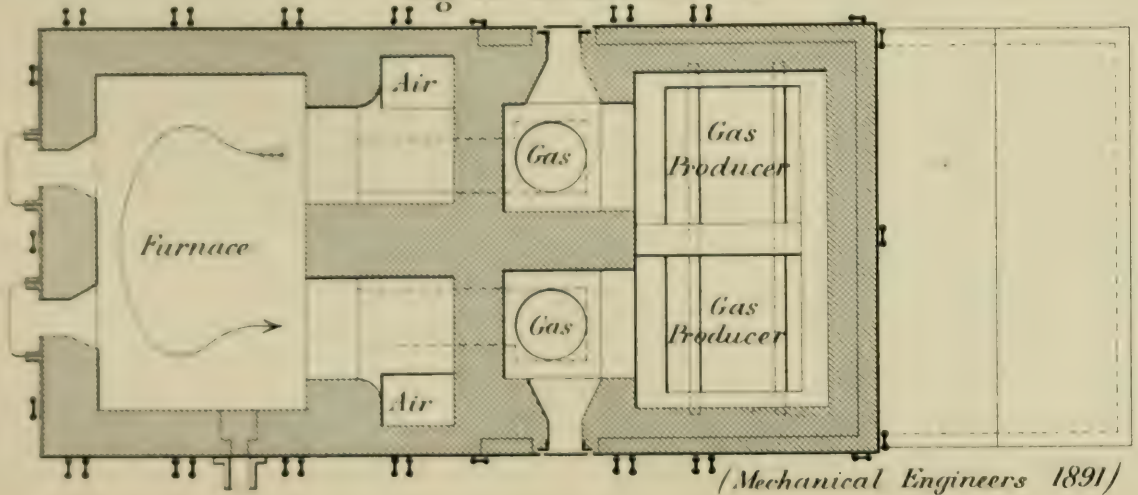


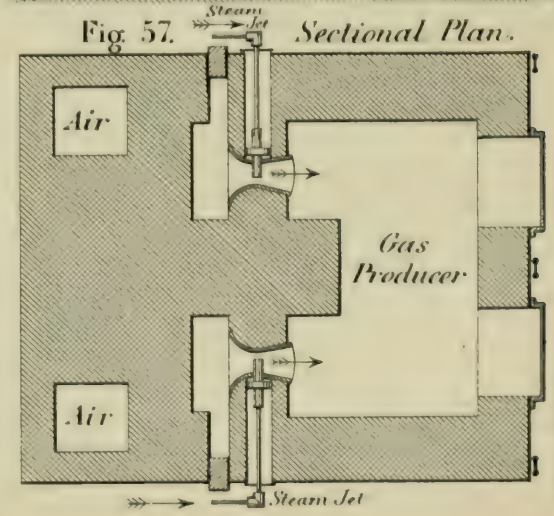
Fig. 55. *Vertical Section.*

Fig. 56. *Sectional Plan.*



(Mechanical Engineers 1891)

Fig. 57. *Sectional Plan.*



GAS FURNACES.

Fig. 58. *Longitudinal Section.*

New Reversing Regenerative Gas Furnace.

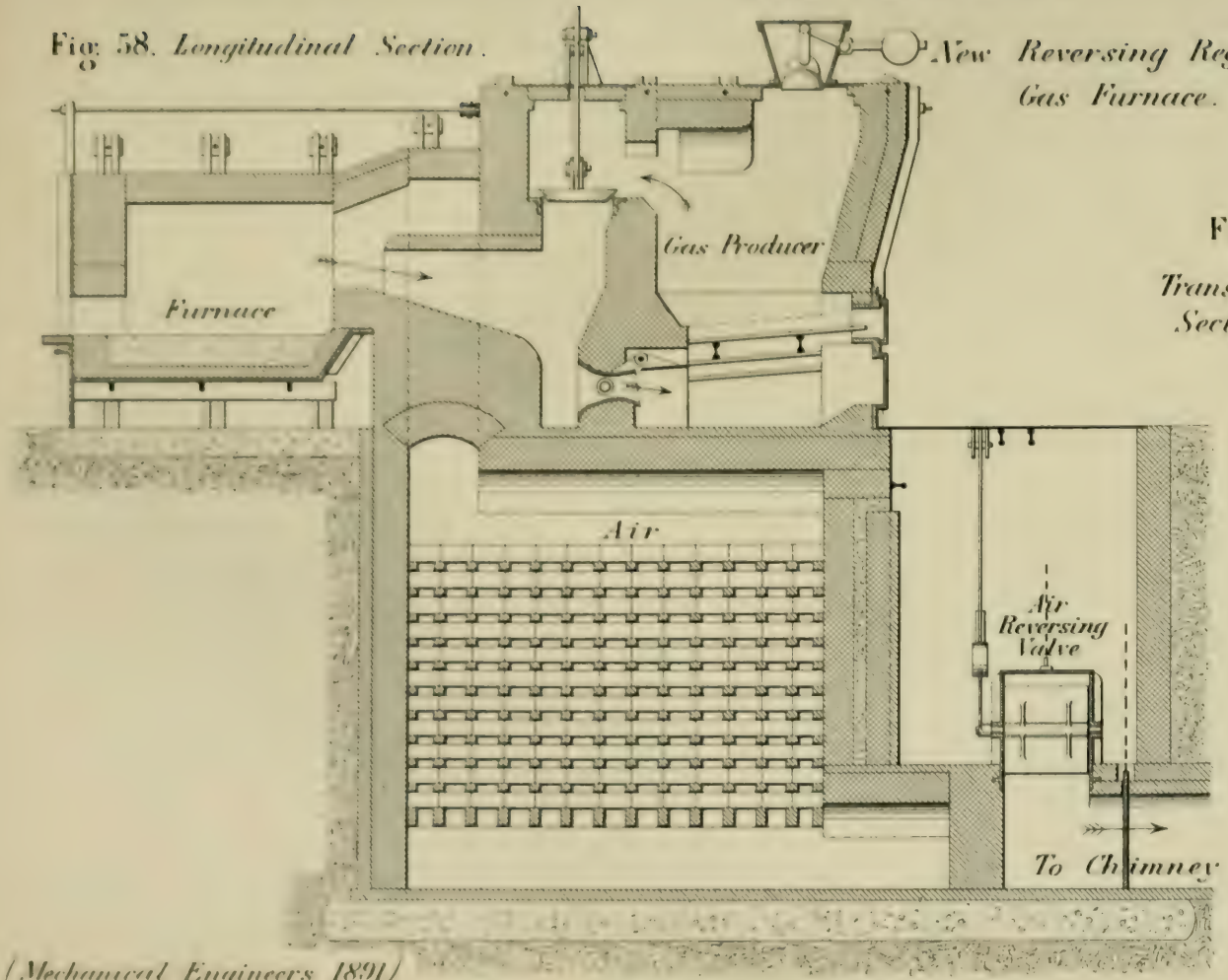
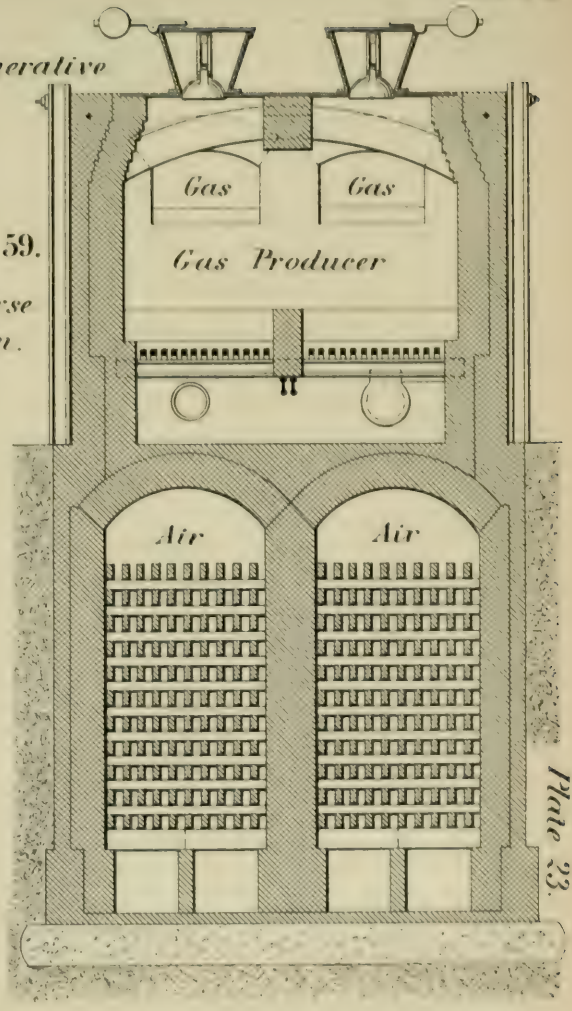


Fig. 59. *Transverse Section.*



(Mechanical Engineers 1891)

Plate 23.

Ramsbottom Revolving Reversing-Valve.

Fig. 60. *Vertical Section.*

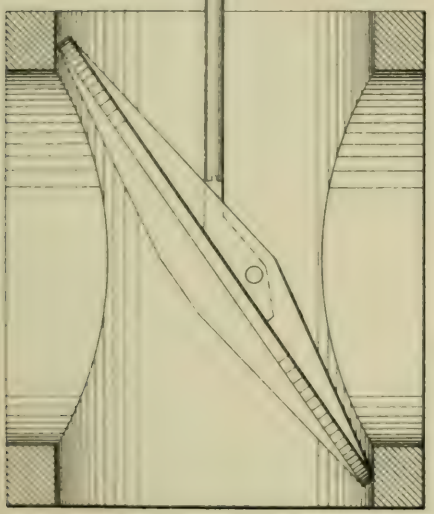


Fig. 62. *Plan.*

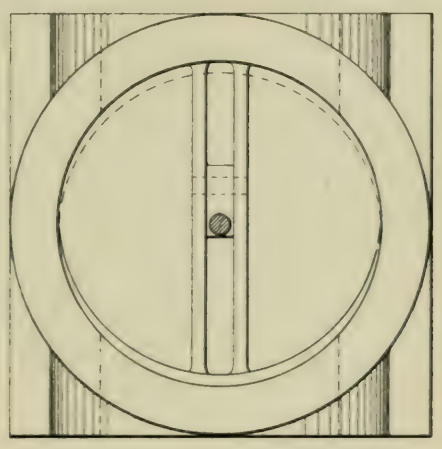


Fig. 61. *Valve reversed.*

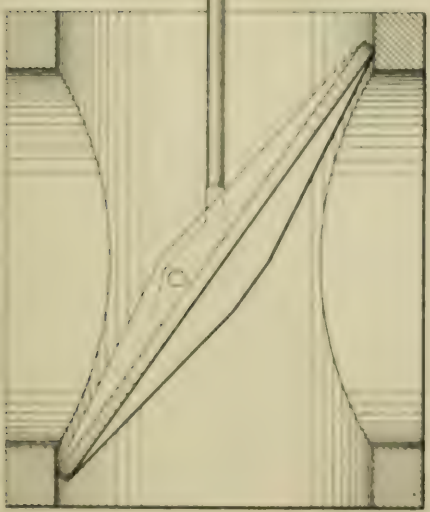
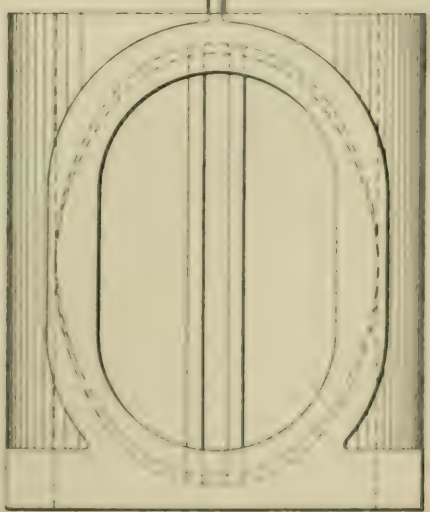


Fig. 63. *Side Elevation.*



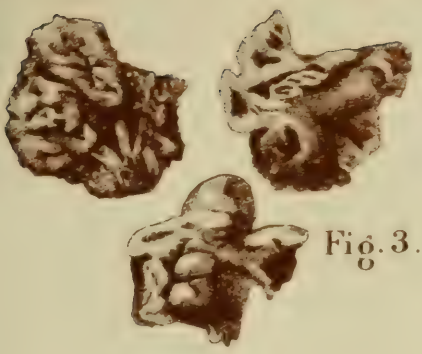
(Mechanical Engineers 1891)

Fig. 1. *Sand Grains in Clusters.*

Fig. 2. *New Sand with Coal Dust attached, and Burnt Sand.*

Mechanical Engineers 1891.

Magnified 50 diameters.



Old Sand.

Fig. 3.

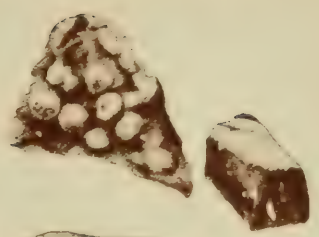


Fig. 4.

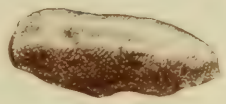


Fig. 5. *Burnt Sand.*

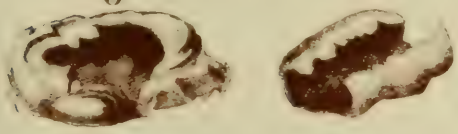


Fig. 6. *Shell round Sand.*

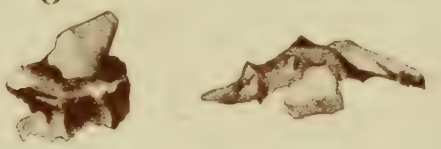


Fig. 7. *Coal Dust.*

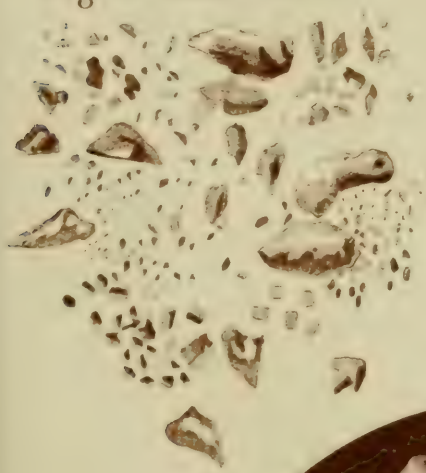


Fig. 8. *Plumbago.*

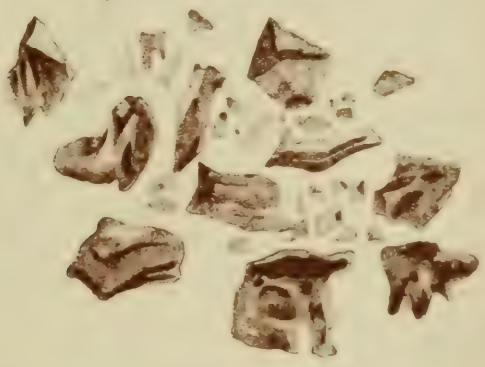
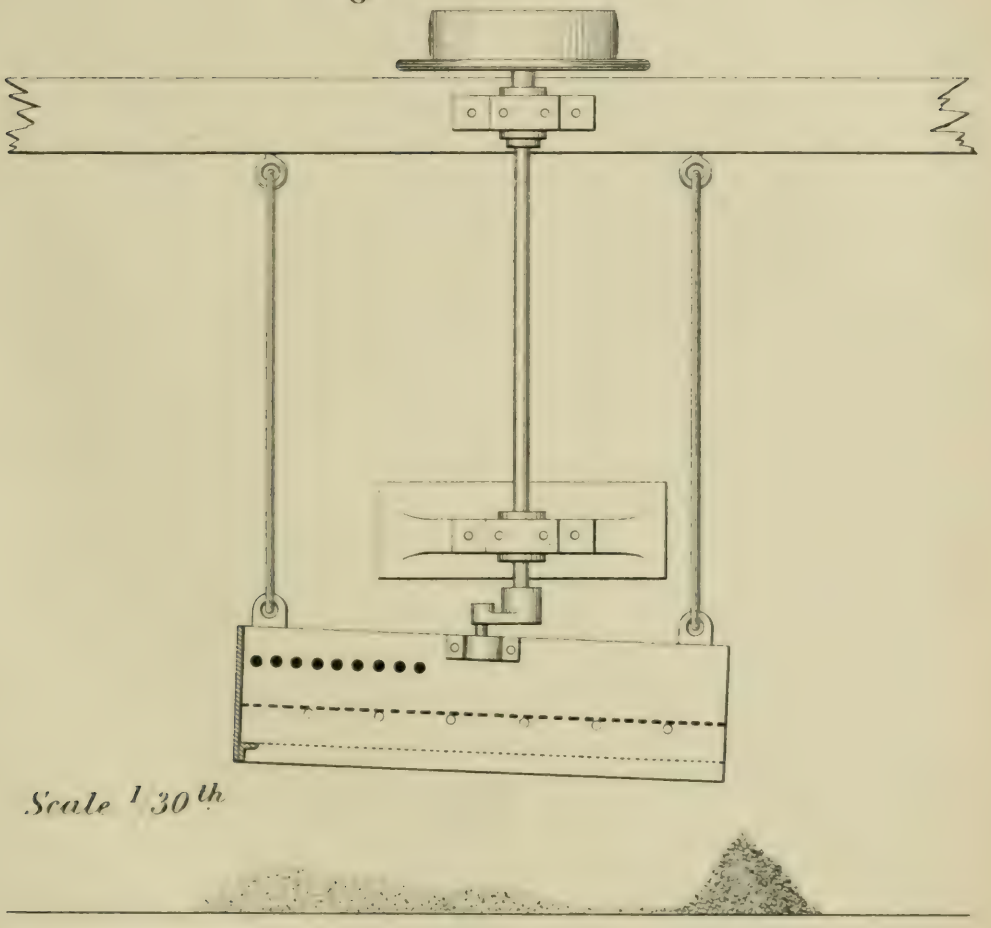


Fig. 9.
Sand after crushing.

Mechanical Engineers 1891.

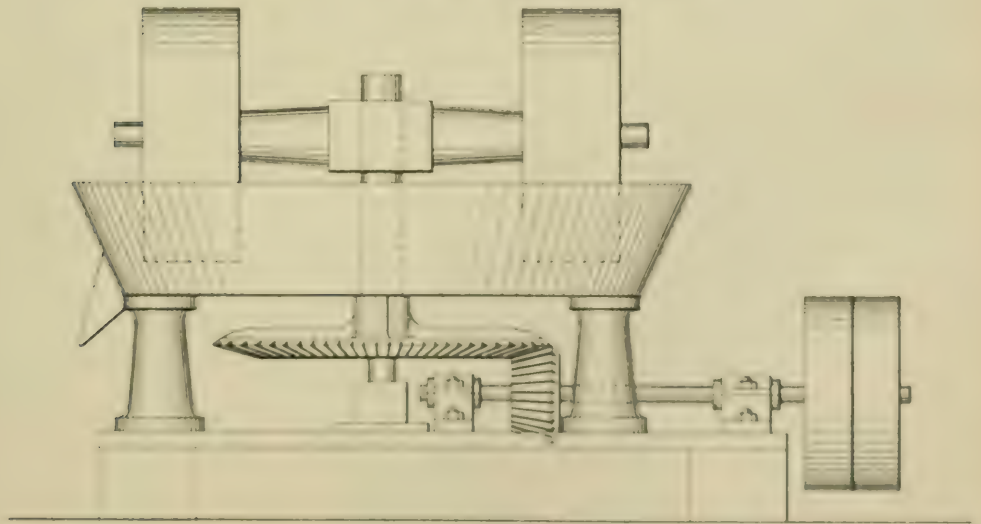
Magnified 50 diameters.

Fig. 10. *Power Riddle.*



Scale 1/30th

Fig. 11. *Roller Mill.*

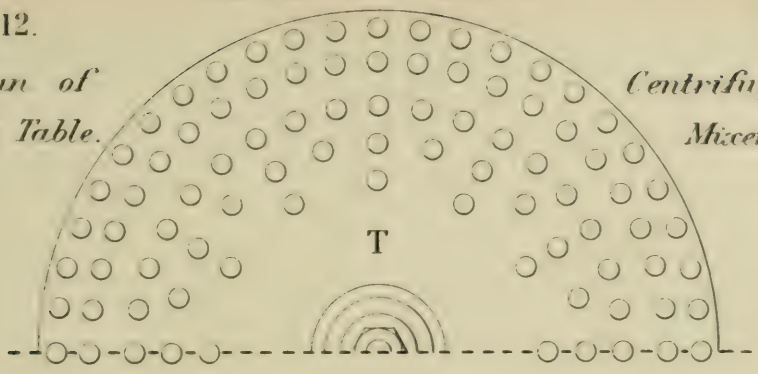


(Mechanical Engineers 1891) *Scale 1/30th*

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet

Fig. 12.

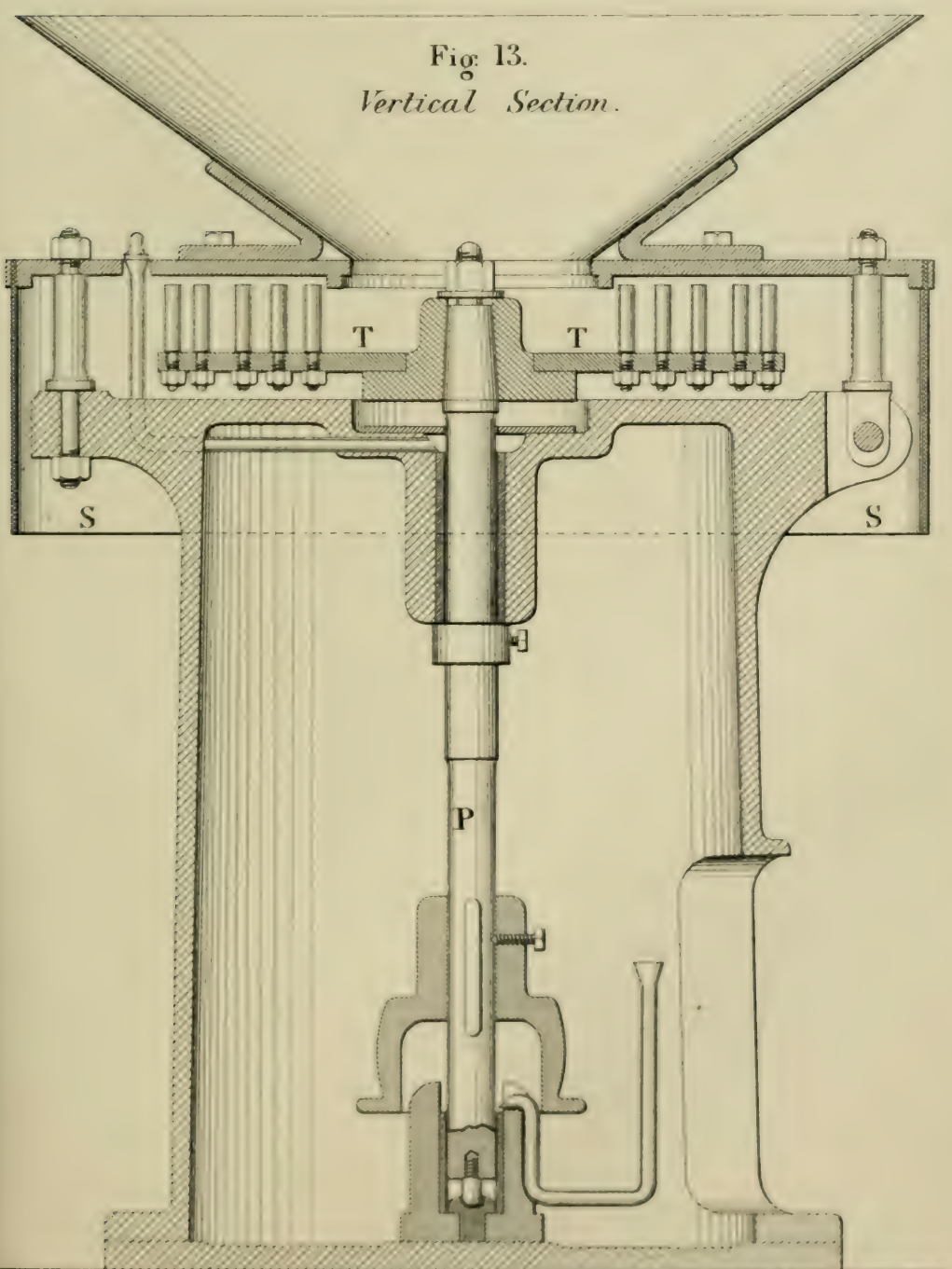
Half Plan of Revolving Table.



Centrifugal Mixer.

Fig. 13.

Vertical Section.



(*Mechanical Engineers* 1891) Scale 1/8th Inches

0 5 10 15 20 25 30

Centrifugal Mixer.

Fig. 14. *Elevation.*

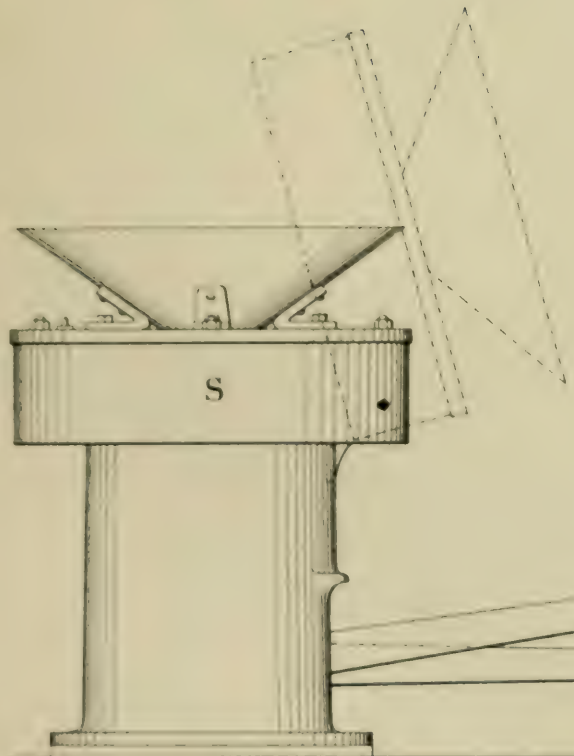
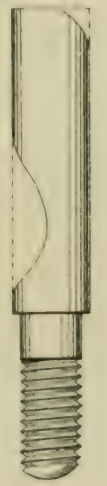


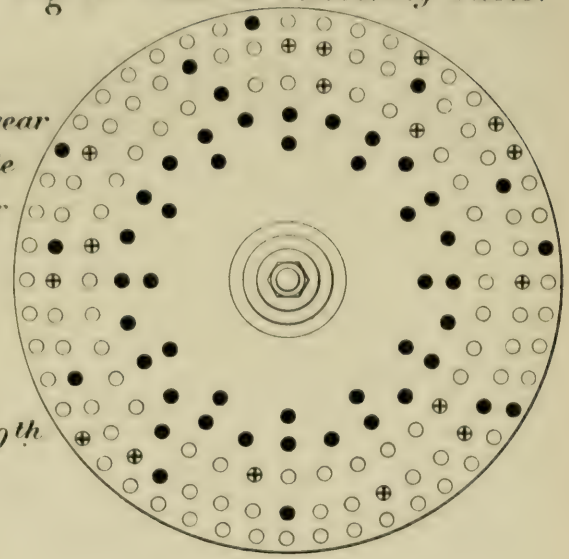
Fig. 16.
Worn Pin.



Half size

Fig. 15. *Plan of Revolving Table.*

● *Much wear*
⊕ *Moderate*
○ *No wear*



Scale 1/10th

(Mechanical Engineers 1891) *Scale 1/20th*

Inches 12 6 0 1 2 3 4 5 Feet

Plate 29.

Institution of Mechanical Engineers.

PROCEEDINGS.

March 1891.

The earlier Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 19th March 1891, at Half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The following Paper was then read and discussed:—

"Fourth Report of the Research Committee on Friction: Experiments on the Friction of a Pivot Bearing."

The following Paper was read, and the Discussion upon it was adjourned to the following evening:—

"On recent Trials of Rock Drills;" by Mr. Edward H. Carbutt, Past-President, and Mr. Henry Davey, of London.

Shortly before Ten o'clock the Meeting was adjourned to the following evening. The attendance was 52 Members and 32 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Friday, 20th March 1891, at Half-past Seven o'clock p.m.; JOSEPH TOMLINSON, Esq., President, in the chair.

The Paper on recent Trials of Rock Drills, read on the previous evening, was discussed.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers, for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at a Quarter past Nine o'clock. The attendance was 30 Members and 37 Visitors.

FOURTH REPORT OF THE RESEARCH COMMITTEE ON FRICTION.

Experiments on the Friction of a Pivot Bearing.

The experiments on the Friction of a Footstep Bearing, which form the subject of the present report, were tried in July 1890 at Messrs. Simpson and Co.'s works, Pimlico.

Description of the Apparatus.—The apparatus employed in these experiments is shown in Figs. 1 to 6, Plates 30 and 31. The bearing experimented on was flat ended and 3 inches diameter, Fig. 5. The vertical shaft carrying the footstep F was geared to a horizontal shaft, Fig. 1, which was driven by a belt from the shafting of the works. Variations of speed were obtained by keying pulleys of various diameters on the horizontal shaft. The bearing B was pressed upwards against the footstep by an oil press P with a plunger 6 inches diameter. This plunger was made a good but perfectly free fit in its cylinder for a length of 9 inches, a number of grooves being turned in the cylinder throughout its whole length at close intervals. The pressure was applied by means of a small hand-pump, provided with an air-vessel, pumping oil out of a tank into the press. It was found that the leakage of the oil past the plunger, even with the highest pressures, was exceedingly slow, requiring only an occasional stroke of the pump to keep the pressure constant; and at the same time the friction was practically nil. Into the top of the plunger was let a piece of hard steel, Figs. 5 and 6, having a conical depression or centre pop, wherein rested a hard steel conical centre, which was screwed into the underside of the plate L that carried the bearing. This plate was circular, Fig. 4, and had a groove turned in its

For previous Reports see Proceedings 1883, p. 632; 1885, p. 58; and 1888, p. 173.

periphery; a small chain C was fastened to the plate and lay in the groove round a portion of the circumference, from whence it led off to a spring-balance attached to the fixed frame of the apparatus: so that the rotation of the plate stretched the spring-balance, and the force tending to turn the plate was thereby indicated. The upper end of the vertical shaft that carried the footstep F had a piston T fixed on it, Fig. 3, which revolved in a cylinder 6 inches diameter. This upper cylinder was connected by a pipe with the cylinder of the lower press P, Fig. 1, so that, whatever oil-pressure there was in the lower cylinder pressing the bearing upwards, there was the same in the upper cylinder pressing the footstep downwards. This was a convenient way of providing for taking the upward thrust upon the experimental bearing.

The footstep having been set running at the desired speed, the hand-pump was worked until the pressure gauge on the oil press P indicated the desired pressure; and the friction was then read off the spring-balance connected with the bearing plate L. The load could be quickly removed from the bearing by opening a cock for discharging the oil from the air-vessel of the pump. This method of applying the load was found to be exceedingly convenient, and to be much superior in that respect to any of the methods used for this purpose in the former experiments made by the Committee.

Lubrication.—The first method of lubrication tried was by introducing the oil through a hole in the centre of the bearing, Figs. 3 to 5, Plate 31, and distributing it through two radial grooves extending from the central hole to within 1–16th inch of the periphery of the bearing surface; these two radial grooves were opposite each other, so that they lay on the same diameter. A pipe U and a passage drilled in the brass connected an ordinary lubricator with the central hole. When the experiments were started, it was found that the bearing took oil out of the lubricator pipe very fast, and delivered it out at the top of the bearing. This suggested the removal of the lubricator, and the soldering of a piece of sheet brass S round the top of the bearing, Figs. 3 and 5, so as to collect the oil and return it by means of a small overflow pipe V into the lubricating pipe.

There was a sufficient space between these pipes to allow the dripping of the oil to be seen, so that the quantity passing could thereby be estimated. Thus the bearing proved to be a most efficient pump, causing a rapid circulation of oil through itself. At first, before the surfaces were worn down to a proper bearing, the oil was observed to be dirty, and charged with particles of brass; as long as this continued, the oil was diverted from the overflow pipe, and run to waste, while fresh clean oil was supplied to the lubricating pipe. When after running a few hours the oil from the overflow pipe was observed to be clean, it was turned into the lubricating pipe, and the bearing was then self-lubricating, and continued using the same oil over and over again.

Results of the Experiments.—The arrangement for lubrication above described, with two radial grooves in a flat bearing of manganese bronze with a steel footstep, was first tried at 50, 128, 194, 290, and 353 revolutions per minute, as shown in Table XVI (page 114), and in the diagram, Fig. 7, Plate 32, in which the load is given in lbs. per square inch of bearing surface, and the friction is in inch-lbs. The coefficient of friction is obtained by dividing the friction in inch-lbs. by the product of the load multiplied by the area of the bearing. The radius of one inch is taken because it is two-thirds of the radius of the bearing. If the flat disc of bearing surface be imagined to be made up of a great number of sectors or triangles radiating from the centre of the circle, the centre of area of any one of these triangles or sectors is at two-thirds of the distance from the apex or centre to the base or circumference. Supposing any one of these triangles to be pulled along in a straight line over a plane surface, the line of force pulling it would pass through its centre of area, because it must be assumed that the friction per unit of surface is the same in all parts of the area of the triangle. It therefore seems reasonable to take two-thirds of the radius of the bearing as the radius at which the force of friction acts, for the purpose of calculating a coefficient of friction which will serve as a comparison between this and the other forms of bearings tried in previous experiments. Of course this view implies the assumption that the

TABLE XVI.—*Experiments on the Friction of a Pivot Bearing. Steel Footstep on Manganese-Bronze Bearing.*

The Friction given is that of one face of the flat circular bearing surfaces, at the effective radius of the face, namely one inch.

Speed.	Load.	Oil Drops per minute	Friction. Total.	Friction. Coefficient.
	Lbs. per sq. in.		Inch-lbs.	
50 revolutions per minute.	20	20	2·77	0·0196
	40	26	4·61	0·0147
	60	40	7·07	0·0167
	80	50	10·25	0·0181
	100	54	15·48	0·0219
	120	56	18·72	0·0221
128 revolutions per minute.	20	79	1·13	0·0080
	40	82	1·54	0·0054
	60	80	2·26	0·0053
	80	83	3·59	0·0063
	100	98	5·48	0·0077
	120	84	7·02	0·0083
	140	90	9·23	0·0093
	160	84	12·82	0·0113
	260		heated and seized	
	300		do.	do.
194 revolutions per minute.	20	196	1·44	0·0102
	40	stream	1·74	0·0061
	60	200	2·15	0·0051
	80	200	2·56	0·0045
	100	200	3·13	0·0044
	120	168	4·41	0·0052
	140	158	6·10	0·0062
	160	168	7·69	0·0068
290 revolutions per minute.	20	Continuous stream.	2·51	0·0178
	40		3·03	0·0107
	60		3·33	0·0078
	80		3·64	0·0064
	100		3·95	0·0056
	120		4·10	0·0048
	140		4·51	0·0046
	160	200	5·03	0·0044
353 revolutions per minute.	20	Continuous stream.	2·36	0·0167
	40		2·72	0·0096
	60		3·08	0·0073
	80		3·59	0·0063
	100		4·00	0·0057
	120		4·51	0·0053
	140		5·23	0·0053
	160		6·15	0·0054

pressure is uniform over the entire surface, and that the friction is independent of the velocity.

After these experiments with the steel footstep on manganese bronze, a white-metal bearing surface was substituted for the manganese bronze, the methods of grooving and lubrication being kept the same. A set of experiments were taken at 128 revolutions per minute, the results of which are shown in Table XVII, and in the diagram, Fig. 7, Plate 32. It will be seen that the coefficient of friction is a little larger with the white metal than with the manganese bronze, but the difference is so small that the results may be looked upon as practically identical; for when the friction is mainly between oil and metal, it should be independent of the nature of the metal. Probably the white-metal bearing was tried before it was worn down to quite as true a surface as the manganese bronze.

TABLE XVII.—*Experiments on the Friction of a Pivot Bearing. Steel Footstep on White-Metal Bearing.*

The Friction given is that of one face of the flat circular bearing surfaces, at the effective radius of the face, namely one inch.

Speed.	Load.	Oil Drops per minute.	Friction. Total.	Friction. Coefficient.
	Lbs. per sq. in.		Inch-lbs.	
	20	60 to 70	1·23	0·0087
	40	„	1·95	0·0069
128	60	„	2·92	0·0069
revolutions	80	„	4·36	0·0077
per	100	„	6·15	0·0087
minute.	120	„	8·77	0·0103
	140	„	10·25	0·0104
	160	„	12·56	0·0111
	240		heated and seized	

An examination of the tables and of the diagram, Fig. 7, shows that at the higher speeds the coefficient of friction is less, owing to the more perfect lubrication, as shown by the more rapid circulation of the oil. That the lubrication and condition of the surfaces were fairly perfect is shown by the low coefficient of friction, which at the

higher speeds with medium loads was in several cases under 0·0050 or 1-200th.

After the completion of these experiments, the manganese-bronze and the white-metal bearings were tested for endurance at 128 revolutions per minute. The manganese-bronze bearing heated and seized on one occasion with a load of 260 lbs., and on another occasion with 300 lbs. per square inch. The white-metal bearing under similar conditions heated and seized with a load of 240 lbs. per square inch.

Besides the experiments of which the results are here given, the steel footstep on manganese bronze was varied by lubricating with three and with four radial grooves; but the friction was from one and a half times to twice as great as with only the two grooves. This fact was carefully ascertained; and the plan shown in Fig. 4, Plate 31, of two opposite radial grooves—or, as they may be called, a single diametrical groove—was adopted for experiment as being decidedly the best.

General Conclusions.—These experiments show conclusively that a bearing of this character is capable of very perfect automatic lubrication, if provision is made for allowing the oil which overflows at the top of the brass to find its way back to the bearing surface at the bottom. Also that a single diametrical groove is better than any other plan. The perfection of the lubrication by this arrangement is proved by the low coefficient, which more nearly approaches the low values obtained in the first experiments, on a cylindrical journal running in an oil bath, than any since obtained.

Discussion.

The steel footstep used in the experiments was exhibited, together with the flat bearing of manganese bronze on which it ran, having two radial grooves and lubricating pipe and overflow pipe.

It was mentioned that the members of the Committee by whom these experiments on pivot friction had been conducted were the President and Mr. Mair-Rumley, in conjunction with Mr. Beauchamp Tower.

Mr. J. Hartley Wicksteed, Member of Council, said the machine used for these experiments appeared to him to be most admirably contrived; and he was glad to know that it was still in existence, and that some further experiments might still be made with it. An interesting feature in its construction was the hydraulic pivot at the bottom, consisting of a cylindrical ram without any hydraulic packings; this being made a free fit in the cylinder, in which a number of circular grooves were turned at close intervals, was said to be almost oil-tight. The bulk of these experiments appeared to have been carried on up to the pressure of 160 lbs. per square inch on the footstep; but as the area of the footstep experimented upon was only one-fourth of the area of the hydraulic ram, the liquid pressure under the ram he imagined would be not more than about 40 lbs. per square inch throughout the bulk of the experiments. That of course was not a severe pressure; it tested the feasibility of this arrangement for keeping a joint oil-tight up to the extent of 40 lbs. only. Some of the experiments appeared to have gone up to 240 and 260 and 300 lbs. per square inch on the footstep, which would bring the pressure on the hydraulic ram up to about 60 and 65 and 75 lbs. The first question he should like to ask was whether the passage of the oil increased to any noticeable extent when these higher pressures were reached: whether the flow of oil that escaped past the baffle grooves in the cylinder was notably more under 75 lbs. pressure than it was under 40 lbs. pressure. He should expect a pressure would pretty soon be reached at which the passage of oil would be copious; and it would be interesting to know up to what pressure such a device as the grooves in the cylinder might be used without losing a large quantity of liquid. In the discussion upon the previous report on collar friction (Proceedings 1888, page 184 and Plate 30) a drawing had been supplied by Mr. Ford Smith of a footstep bearing which was similar in principle to that now tried by the Committee: that is, it was surrounded by a chamber

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which returned the oil to the central feeding-hole at the bottom, and the oil circulated freely round the pivot, and was constantly coming out at the top and entering again at the bottom. But in that case the weight of the shaft which rested upon the footstep bearing had been stated to give a pressure on the footstep bearing amounting to as much as 455 lbs. per square inch. From the present report it appeared that the bearing now tried had seized at 240 lbs. per square inch; and there was no record of what had happened in the interval between 160 lbs. and 240 lbs. He presumed therefore that 240 lbs. was the first point at which seizing had been noticed, and that the intermediate pressures if they had been noted would simply have carried on the curve in the diagram, Fig. 7, Plate 32, in something of an even line, and that consequently it was not necessary to record the coefficients for the intermediate pressures. At any rate he was glad that the point where the seizing took place had been recorded. But were the resources of engineers exhausted when the pressure of 240 lbs. per square inch was reached on a footstep bearing? In the instance given by Mr. Ford Smith, there were four loose revolving discs of hardened steel, inserted in the footstep bearing and truly ground up; and if by the device of putting in four such discs, or a larger succession of them, one on the top of another, the pressure on the thrust bearing might be so far increased as appeared to be the case in Mr. Ford Smith's recorded experiments, it seemed highly important that this should be ascertained with precision. If it had not yet been exhaustively tried, he suggested that it might still be tried in the existing apparatus, which was now in the hands of Professor Beare, at University College, London. It seemed pretty clear that speed must be an element in the seizing of bearings; and although the speeds dealt with in these experiments were not high, it appeared to him that if by means of a number of loose discs the speed, moderate as it was, were reduced much lower still, the conditions of the friction would be materially altered thereby. From the previous report on collar friction (1888, page 178) it appeared that the collar began to seize at something over 80 lbs. per square inch. He had then mentioned (page 190) an example, which he thought was pretty well ascertained, of the thrust collar of a

drilling-machine spindle, which worked constantly at a pressure of about 336 lbs. per square inch, or four times as much as the collar experimented upon by the Friction Committee. It worked however at a slower speed, and there was also the further difference that, instead of being a washer with no stem to it, it was a collar upon a shaft which had a stem; the lubricant was fed from the centre, and had the opportunity of flying outwards from the collar, but no opportunity of escaping inwards. That was a material difference, apart from the difference of speed. There must be instances, he thought, of pivots working at slow speeds, which stood much higher pressures without seizing than would be expected from the experiments now recorded. For instance, a forging weighing twenty tons was a common piece of work to be centred in a large lathe; and there must then be ten tons resting upon each of the lathe-centres. The fast head-centre went round with the shaft, but the loose head-centre was stationary; and the piece of work, which was presumably of a softer material than the hardened point of the loose centre, was revolving upon it. The horizontal sectional area of the portion of the loose centre that penetrated the work and carried the load of ten tons was not much more he thought than one square inch. It was true the speed was very slow, in all probability not more than half a foot or perhaps a foot in a minute; but still there was the fact of ten tons being supported and lubricated sufficiently for the metals not to seize each other, under a pressure, he supposed, of as much as ten tons per square inch. Unless therefore some answer could be given to his remarks, he hoped that some further experiments would be made with the apparatus, in respect to the effect both of loose discs, and possibly of some kind of curved end for the footstep, instead of the flat end; and also to show how much pressure could be carried at very slow speeds.

Mr. J. Veitch Wilson, having himself tried at different times in a crude way to determine some of the questions regarding friction which were now being dealt with by the Research Committee of the Institution, had been looking over with much interest the reports of their previous experiments, in one of which he observed notice had

(Mr. J. Veitch Wilson.)

been taken of the fact that the temperature of the bearing had much to do with the coefficient of friction, and that the latter diminished as the temperature rose. He therefore enquired at what temperature the present experiments had been conducted, whether at one uniform temperature; and whether, if one uniform temperature was assumed, some means had been provided for ascertaining and noting that that temperature was not exceeded: because it seemed to him that, with the varying speeds at which these experiments had been tried, the probable consequence of variation in speed would be that a considerable difference in temperature would be developed in the bearing in a short time. And the effect of an increasing temperature in the bearing would be to diminish the thickness or body of the oil, that is its viscosity, and to reduce the drag and thereby to reduce the coefficient of friction. Referring to the Committee's first report in 1883, this conclusion was exemplified by Table IX (page 651) giving experiments tried with lard oil at different temperatures. At 90° Fahr. and at 100 revolutions per minute under a pressure of 100 lbs. per square inch, lard oil gave a coefficient of friction of 0·0034. But when the temperature of the bearing was permitted to rise to 120°, the other conditions remaining the same, the coefficient of friction ran down to 0·0024, which from Table IV (page 646) was seen to be almost the same coefficient of friction as that produced by sperm oil at 90° Fahr., under similar conditions of speed and pressure, namely 0·0025. This fact had led him to look up a few tests which he had made with regard to the viscosity of oil at different temperatures. Representing the viscosity according to a scale upon which the figures were merely arbitrary for the purpose of comparison, he had found that, while sperm oil at 60° Fahr. had a viscosity represented by 50, its viscosity at 70° had diminished to 45, and at 120° it had run down to 30. From these figures therefore he thought it was not unfair to assume that at 90°—the temperature at which the Committee's experiments just quoted had been tried—the viscosity of sperm oil would be somewhere about 40, perhaps a little under. Lard oil under the same test and according to the same scale gave at 60° a viscosity of 100, at 70° its viscosity had diminished to 80, and at 120° it had run down to 39: that is to say,

the viscosity of lard oil at 120°, at which it gave a coefficient of friction of 0·0024, was probably about the same as that of sperm oil at 90°, at which sperm oil gave practically the same coefficient of 0·0025. Thus the Committee's experiments on friction and his own on viscosity appeared to be mutually consistent in the results independently arrived at. In view therefore of the circumstance that the effect of friction was to produce heat, and that the effect of heat was to reduce the coefficient of friction, the question naturally arose whether the expenditure of power necessary to increase the heat of the bearing was fully compensated for by the lower coefficient of friction thence resulting, or whether there was still an excess of power expended in producing the higher temperature. This was a question which he had frequently put to engineers, and it seemed to him to be a leading point in connection with experiments upon friction of bearings.

Professor ALEXANDER B. W. KENNEDY, Vice-President, thought if there was any fault to be found with the report now presented it was one which might also be found with others of the reports drawn up by Mr. Tower, namely that he had really condensed so much into such a short space that the members would be pleased if he had given the results at twice the length, and had included a great many more particulars. That was a fault which was not often fallen into, and happily it was easily to be remedied. The question raised by Mr. Veitch Wilson he hoped might be dealt with as far as possible in further experiments with the present apparatus; there was no doubt that additional information upon that point would be of considerable value.

One or two other points had also occurred to himself, as to which he should also like some more information, such as he was sure Mr. Tower had the means of giving. For instance, in the first two sets of experiments at the slower speeds of 50 and 128 revolutions per minute in Table XVI the coefficient of friction at any given load was much greater than at the higher speeds of 194 to 353 revolutions. Taking the load of 100 lbs. per square inch, the coefficient at 50 revolutions per minute was 0·0219, and at 128

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revolutions it was 0·0077; but at 194 revolutions it was 0·0044, and it then rose a little, but did not vary much up to 353 revolutions. At the same time he noticed that the first two sets of experiments, at 50 and 128 revolutions per minute, were made with counted oil drops, and the last three apparently with a more or less continuous stream. It would be important to know whether the differences in the coefficients were due to differences of lubrication: whether the lower coefficient could have been got at the slower speeds if equally good lubrication could have been obtained at the slower speeds; or whether the difference of coefficient arose from some cause which had actually to do with speed. If it had to do with the lubrication, it was obviously highly advisable—unless there was some reason to the contrary, of which he did not know—that the slower speed experiments should be made again with the same lubrication as the quicker speeds. No doubt this had already been thought out; but it would be interesting to have on record what Mr. Tower had to say about the matter.

Like most engineers he remembered hearing at an early stage of his apprenticeship that footstep bearings would carry fabulous loads, whereas the present experiments proved that, even although perfectly lubricated, they would carry only a small load. As pointed out by Mr. Wicksteed, there were plenty of footsteps which carried a much greater load than in these experiments, but which were perhaps not lubricated anything like so efficiently. Hence the question arose whether the difference in the load was due to difference in form or construction of the footstep; and the probability seemed to be that it was really due to a large extent to the distribution of the motion among a number of rubbing surfaces, by the insertion of loose discs below the footstep, a practice which for a long time had been common in good work. It would be quite worth while, he believed, for the Institution to arrange for making experiments on some such footstep as this.

An interesting theoretical point raised by Mr. Tower in the present report was as to what the mean radius of pressure in a footstep bearing really was. The assumption that the centre of pressure was at two-thirds of the radius implied of course that the

pressure was uniformly distributed to start with, and remained uniformly distributed afterwards. But when two revolving surfaces like those of a pivot bearing were set in motion under a uniform pressure per square inch, the immediate result would be that the outside would begin to wear first; and then the pressure per square inch at the outside would become less than nearer the centre, and the ultimate conditions would be conditions of uniform wear and not of uniform pressure. If that was so, two consequences would seem to follow. The first was certainly that the centre of pressure would be at half the radius, instead of two-thirds. The second was that the most perplexing thing would happen in the centre of the bearing, because it was clear that the intensity of pressure would be enormously great at that part, far beyond the limit of elasticity of the material, and the material would presumably be crushed. No distinct effect of that kind however was noticed in a pivot bearing: so that there must be something wrong in that way of looking at the subject; and the matter was one which had perplexed him not a little. In the case of an annular surface, or ring without a centre portion, it was probably right to take the centre of pressure as being the arithmetical mean between the outside and the inside radius; and in the case of a footstep he thought, subject to correction, that probably the mean radius of friction was more nearly half the radius of the pivot than two-thirds. That however was perhaps rather an academic question than one of great practical interest.

The diagram of the results, shown in Fig. 7, Plate 32, appeared to have been drawn by plotting certain particular points, and then drawing a wavy curve through them. That was a perfectly legitimate thing to do; but when it was done, the curve did not represent anything except the particular results of special experiments. A curve suitable for general use, Mr. Tower would probably agree, would be constructed by plotting exactly the points obtained in experiment, wherever they might come, and then drawing the mean curve which lay fairly between them. He should therefore be glad if, in addition to marking on the diagram the exact points corresponding with the different experiments, Mr. Tower would if possible draw

(Professor Alex. B. W. Kennedy.)

the fair curves in accordance with his own views of the actual results. Any individual member of the Institution might have some difficulty in doing this satisfactorily for himself; but Mr. Tower, having carried out the whole of the experiments, and himself worked them all out, would be able to draw a curve which might be actually fair enough to be of considerable use.

It would be interesting if some details could be given of the experiments mentioned in page 116 with three and with four radial grooves in the face of the bearing, which were stated not to have turned out so well as the two opposite radial grooves or single diametrical groove. That seemed to him an important practical point in footstep bearings.

Every member he thought would agree that the present report, with the mass of information it contained in such a small space, was well worthy of a place beside the former reports received from the Research Committee on this subject, whereby he was quite sure the expenditure by the Committee upon the work that they were doing was more than justified.

Mr. WILLIAM SCHÖNHEYDER thought the experiments now reported came opportunely at the present time, because for a long time past it had been generally believed that a footstep would carry almost any weight; and as the result of that belief it was not uncommon to see in mills and turbines footsteps running hot simply because the weight which they were capable of carrying was so much over-rated. The present experiments, which had been conducted with so much care, confirmed the view which he had himself entertained, that a footstep was a bearing of a similar nature to that which was met with for example in the slide-block of a cross-head. It was well known that in a cross-head slide-block the amount of weight which could be carried per square inch was not more than one-tenth of what could be carried by a cylindrical journal. Whereas the latter could carry from 400 to 600 lbs. per square inch, a cross-head slide-block which was constantly wiping the oil away could not carry much more than 40 to 60 lbs. per square inch. From the experiments now reported, it appeared that, although the pressure which the footstep carried went up as

high as 160 lbs. per square inch, still the best pressure, at any rate at moderate speeds, was not more than from 60 to 100 lbs. per square inch. It further appeared, as pointed out in the report, that the coefficient of friction diminished as the amount of lubrication increased. The number of oil drops counted per minute in the experiments he presumed were not drops of fresh oil supplied, but were the number that fell from the overflow spout, and ran back again under the bearing. That being the case, it occurred to him that there might perhaps have been some difficulty in regulating the quantity of oil supplied to the bearing; and any further experiments he would therefore suggest might be made with oil pumped in continuously under the bearing, as had been the daily practice in certain heavy footstep bearings, which were thereby enabled successfully to carry a sufficient load and to continue running cool under it. That might be readily done in the present case, and it would then be seen what pressure such a footstep would carry.

With regard to the plan of introducing a number of loose discs underneath the footstep, the result would be that the relative speeds of the pairs of rubbing surfaces would be much reduced, provided some means could be taken for ensuring sufficient lubrication between them all; otherwise it would be found that one disc would cut and stop running, while the others would go on; and although by this means the bearing was helped along a little under a heavy load, yet, in order to get proper results, there must be good lubrication introduced between all the discs. So small a difference between the coefficient of friction with the white-metal bearing and the manganese-bronze would seem rather surprising, were it not for the explanation suggested in the report, that the friction was hardly between metal and metal, but mainly between oil and metal.

With regard to the diagram shown in Fig. 7, Plate 32, it appeared to him that the friction in inch-pounds was not what was wanted to be known, but rather the coefficient of friction: and if the latter had been plotted out so as to show how it varied according to the different pressures per square inch and the different speeds, that would have been more useful, because it would then have been seen where was the lowest point in each curve, and where consequently

(Mr. William Schönheyder.)

the coefficient of friction was least. It seemed to him that a diagram of that sort could be simply made, and would be of greater use than the diagram now shown. [See Fig. 8, Plate 32, added accordingly.]

Mr. HENRY DAVEY considered the mounting of the pivot bearing in these experiments was under a most favourable condition, because it was supported upon a centre point, and was what might be called a free bearing, somewhat different from bearings as they were made in common practice. It was not rigidly fixed, and therefore could accommodate itself to an even distribution of load over the entire surface. That, he imagined, was the most favourable condition for the running of a bearing of this kind. The amount of weight carried by the centres of lathes, alluded to by Mr. Wicksteed (page 119), had always been a great puzzle to himself, because the lathe centres certainly did carry a much heavier weight than it would be supposed they ought to carry. There was a marked difference however between the condition of supporting the load on the centres of a lathe and the condition of a footstep bearing. Apart from the end thrust of the lathe centre, which might be greater or less than half the load, according as the angle of the conical point was greater or less than a right angle, the weight was carried only on the upper surface of the cone, while the lower surface probably was scarcely touching.

Mr. J. LYONS SAMPSON, referring to the preference expressed in page 116 for "a single diametrical groove," enquired whether the experiment had been tried of working a bearing of that kind without any grooves. As far as his own individual experience had gone, he had found oil grooves to be rather an objection than otherwise; they served to collect dirt. He had never met with any difficulty in getting oil to run between the rubbing surfaces of a pivot bearing without any grooves, when fed with oil at the centre. In the report it was stated that when more grooves were used the friction was greater: which would tend to confirm the view that he had taken. It had also been shown in the former experiments made with cylindrical bearings that the seat of pressure was the wrong place to lubricate the bearing, or to introduce oil. Cutting grooves across the

face of a pivot bearing he thought had rather a tendency to let the oil escape from between the surfaces than to secure their lubrication. There was naturally a tendency for the oil to work its way from the centre to the outside. If a small solid sphere were introduced between the two rubbing surfaces of a footstep bearing, it would soon reach the outside. The action of the rubbing surfaces on the molecules of the oil he thought was much the same; and therefore without the grooves the oil would be found to work from the centre to the outside.

Another point, in which he had been rather anticipated by Professor Kennedy (page 123), was that, owing to the difference of surface speed near the centre and near the circumference of a footstep bearing, the bearing should be run during a considerable period in order to get a reliable result. Time entered largely into the value of the experiment: for while at first no doubt the pressure was uniform all over the surfaces, after longer running they would become more worn towards the circumference, and the pressure would thereby become accentuated near the centre, and the conditions altered.

Mr. WILLIAM S. LOCKHART gathered from the report, and from the drawings shown of the experimental apparatus, that flat surfaces were recommended to be used for pivot bearings, in preference to any of the many other shapes which under various circumstances had been employed by engineers for footstep bearings. The oil pipes and hand-pump described in the report appeared to be intended simply for putting the pressure upon the bearing; and he did not find any suggestion made that the bearing itself should be lubricated with oil under pressure. It would be interesting to know how the conclusion had been arrived at that the best surface for a pivot bearing was a flat surface; and whether bearings of other shapes had been tried. In his own experience he had found that a hemispherical steel toe, let into the bottom of a vertical spindle, and working upon a perfectly flat steel bearing surface beneath, gave good results, both surfaces being tempered as hard as they could be made, and running in oil. According to theory, if the bearing surface were reduced to a mere centre point, there would practically be no motion at all; but in

(Mr. William S. Lockhart.)

practice of course before that point was reached the pressure would become too great. It seemed to him that if the pressure between the two surfaces in contact became excessive, the oil would not be able to get in between them, and the bearing would not be lubricated at all. Loose discs he knew were largely used for footstep bearings, and when made with slightly tapered edges, it was easy for the oil to get in between them; and it had always appeared to him that perfectly smooth tapered discs without oil grooves allowed much better lubrication than a flat bearing with oil grooves. On these points it would be interesting if experiments could be tried for ascertaining what did take place under various circumstances.

Mr. GEORGE CAWLEY observed it was stated in page 113 that "the bearing proved to be a most efficient pump, causing a rapid circulation of oil through itself." But further on it was stated in page 116 that when tested for endurance at higher pressures the bearings heated and seized. When this occurred he presumed that the pumping action had failed; and if that were the case, it would be interesting to know what exactly was the condition that caused its failure: whether it was the extra weight only, or whether it was the increased temperature and the diminished viscosity of the oil; or how far each of these three causes—load, temperature, and viscosity—retarded or stopped the self-lubricating action.

Mr. BENJAMIN WALKER, Member of Council, remembered that in 1852 a large flax-mill in Leeds, owned by Messrs. Marshall, had been furnished with a large pair of engines having an unusually heavy fly-wheel, heavier than the makers themselves recommended; and the shaft of this fly-wheel was at first a great source of trouble. Though there was a man always on the look-out to oil the shaft whenever required, the whole mill and all the workpeople would be stopped every now and then, because the fly-wheel shaft had got overheated. Having been asked to examine the shaft, and see what in his opinion would cure the trouble, he had advised the substitution of a well-made shaft of Yorkshire iron, and that the bearings should be made much better and much harder than the existing bearings. The

workmanship he considered was not at all good enough for the heavy load to be carried; and if better workmanship and better material were put in, he believed the trouble would disappear. The disadvantages were certainly great, owing to the enormous cost of changing so large a shaft, and the high price to be paid for the new shaft. Phosphor-bronze did not exist then, but the bearings were cast from very hard gun-metal, so hard that great difficulty was experienced in boring them. The greatest possible accuracy was bestowed upon the shaft to make it fit perfectly, so that the bearings should be thorough and good. The time of starting the shaft to work was a time of great anxiety to every one as to what would be the result. It had not run more than an hour before he felt that it was beginning to get warm. It was therefore stopped for the rest of the day, and before the next morning he got a small hand-pump, and connected its delivery with each bearing, so that every half-hour a man could give it a good douche of oil. The oil went in at the bottom of the bearing. The pressure exerted by the hand-pump would be something like half a ton per square inch to force the oil in through the small hole, and squeeze it through between the bearing surfaces. No further trouble occurred with the shaft; it was only necessary to force the oil in at regular intervals, and it went on working all right; it was good workmanship and good material, and was adapted for the heavy load it had to carry. The weight of the fly-wheel and shaft together amounted to $35\frac{1}{2}$ tons; the shaft was $12\frac{1}{2}$ feet long, and the two bearings were about 8 feet apart from centre to centre, with the fly-wheel midway between them, and were each 18 inches diameter and 30 inches long: so that the nominal load, according to the usual mode of calculation, was about 74 lbs. per square inch.

The successful running of a bearing depended not merely upon the load it constantly carried, but also upon the speed and the quality of the workmanship. The load carried by a lathe centre, which had been referred to by both Mr. Wicksteed and Mr. Davey, seemed perfectly marvellous until it was remembered that care was always taken by the turner to make grooves or holes with the chisel in the end of the shaft or casting, for enabling the grease to get down to the centre pivot; and care was always taken also to put plenty of oil

(Mr. Benjamin Walker.)

on at the beginning. Moreover the strongest lathe-centres were made of hard tool-steel, so hard that a file could not touch it. It was therefore owing jointly to the hard material, the slow speed, and the ample lubrication, that the lathe-centre carried so enormous a weight. If he had to make a vertical shaft for carrying a great load, he should never think of making it with a plain flat end, like that tried in these experiments, but should prefer to taper it down to a centre point like a lathe-centre. It was not so common now as formerly to use vertical shafts, because it was more common in mills to drive with ropes or belts than with bevil gearing; but it would be found that some of the least troublesome vertical shafts ran on a conical footstep. In most cases the foot of the shaft had a piece of very hard steel let into it, as hard as flint or glass, and that too worked upon another very hard piece of steel, so that the bearing greatly resembled a lathe-centre in regard to the load it was capable of carrying. It was well known that there were thousands of shafts at work which depended for their lubrication upon getting hot; the bearing had to get hot before it could get thoroughly lubricated. But that was an unreasonable way of lubricating, and modern science had shown that the proper way was so to bore and turn the bearings and their necks as to allow access for an ample supply of oil to the rubbing surfaces. This was the plan followed in the best railway practice, in which the successful running of the heaviest rolling stock in the fastest trains was largely due to good workmanship, good fit, and good material, along with ample bearing surfaces and a liberal supply of oil. In 1847 he remembered going into the question of blowing fans for foundry and other purposes, which in those old days used to absorb a terrible amount of power to drive them. As the result of experiment he found that all that had to be done was to reduce the diameter of the fan spindle, so that the rubbing surface carrying the weight should travel at a slower speed; and at the same time to increase the length of the bearings, and to make the spindle of hard material and good workmanship. Whatever the load upon the spindle, if the surface speed in the bearings could be reduced to one-half, it was just as good as running with half the load at the original speed. The first question that mechanical engineers

usually had to consider was cost; and although it might sometimes seem more profitable and convenient to make a rubbing surface big and to let it depend for its lubrication upon getting hot, than to make the workmanship good and to provide good lubrication, yet the best rule was good workmanship, true surfaces, and sound material. These means would result in producing the least amount of friction, and in getting the greatest amount of work out of the machinery.

Mr. E. R. DOLBY asked whether any record had been taken of changes in the shapes of the rubbing surfaces during these experiments, namely in the face or bottom of the footstep, and in the face or top of the bearing; because it appeared to him that such a record would to a great extent settle the question raised by Professor Kennedy (page 123) as to the greater wear at the outside. He should also like to know whether any experiments had been tried with pivot bearings made in the form of a Schiele anti-friction curve, so as to proportion the amount of load per square inch to the speed at which that particular portion of the surface travelled. It would also he thought be a good thing if a bearing of magnolia metal were tried; for although he had not himself had much practical experience of it, he understood some good results had been obtained with it in steam-ships.

Mr. BEAUCHAMP TOWER, in reply to Mr. Wicksteed's question (page 117) about the oil ram, said the leakage of oil past the ram was very small indeed up to the pressures that were used, which did not exceed 40 lbs. to 60 lbs. per square inch on the ram. The same construction of ram he had no doubt could be employed quite usefully with an oil-pressure up to 100 lbs. per square inch, and the leakage would be of small importance, that is, not exceeding such a rate that it could easily be supplied by working a few strokes of the hand-pump every two or three minutes. The plan certainly answered perfectly, and the friction of the ram seemed to be nothing at all. Although the ram could be turned round with the hand quite easily, yet the leakage past it during the experiments was not at all inconvenient.

(Mr. Beauchamp Tower.)

The principle of Mr. Ford Smith's footstep bearing (page 117) was the same as that of the arrangement described in the report, in regard to the use of a single diametrical groove for lubricating the rubbing surfaces; but it had five pairs of rubbing surfaces instead of only one pair. No doubt five were better, because there was five times more surface and more freedom: there were indeed five bearings in the place of one bearing, and those five bearings would do better than a single one; but the principle was exactly the same as of the single bearing described in the report, and no doubt the action of the lubrication was the same in both cases.

In regard to the enquiry as to how the friction increased in the interval from the recorded friction up to the point of seizing (page 118), extreme care had to be taken with the bearing when it had been got into a good state. It often took several days' running before it was got into a thoroughly good working state; and it was then necessary to look at it frequently and to be most careful to avoid running any risk of its being damaged by being overloaded. If it were overloaded, it began seizing; and it then took three or four days' running before it could be got back to its former good state. The intermediate frictions had therefore not been accurately recorded. All those frictions that had been recorded were perfectly safe amounts, which the bearing could be relied on to carry without risk to itself. After trying these experiments the bearing had then been gradually loaded up until it did seize. It showed symptoms of being uncomfortable some time before it seized, the friction rising with spasmodic jerks; and the figures varied so much, that it was not possible to get any satisfactory record as to what was the exact increase of friction in the intermediate stage.

With regard to speed, both Mr. Wicksteed (page 118) and Professor Kennedy (page 121) had referred to the fact that apparently the speed affected the coefficient of friction, and that the coefficient of friction seemed to diminish at higher speeds. It certainly did diminish as the speed was increased up to 290 revolutions a minute; and he attributed that result to the very perfect lubrication. Professor Kennedy had also suggested (page 122) that the lubrication might have been regulated, so as to use as much oil at the slower speeds as at the

quicker; but this it had not been practicable to do, because the actual rate of lubrication was the rate which was natural for the speed: it was the rate at which the bearing itself took the oil, and at the quicker speeds it could not be prevented from taking it at the higher rate. As the bearing ran faster, so it took oil more quickly, and no doubt lubricated itself more perfectly.

In the previous collar-bearing experiments referred to by Mr. Wicksteed (page 118), it must be remembered that the collar having so narrow a surface was an extremely difficult bearing to lubricate, and did not at all lend itself to perfect lubrication. That was the reason, he thought, why it had carried such a small load; and as far as he could learn from the experience of ordinary collar bearings of screw shafts in steamers, it was found not safe to put a heavy load upon them.

With respect to lathe-centres, which in some cases were supposed to carry perhaps as much as ten tons per square inch, he imagined that under such a load there could be no true lubrication. The metals must be in contact, and continual abrasion be going on, the soft metal wearing away in contact with the hard steel centre; but owing to the slow speed and the consequent small amount of energy turned per minute into heat, and also to the comparatively small number of revolutions which such a bearing made during its whole time of work, neither heating nor wear was sufficiently large to cause inconvenience.

In reply to Mr. Wilson's enquiry (page 120) as to whether in these experiments there had been any means of regulating the temperature or recording it, as a matter of fact this had not been done. In the first experiments with the cylindrical bearing (Proceedings 1883, page 632), the question of the effect of temperature on lubrication had been most carefully and elaborately gone into; and it had not since been thought necessary to repeat that portion of the experiments, as that point was considered to have been completely elucidated. The value of different kinds of oil having also been tried at the same time, it had not been thought needful to repeat the trials, because that question had then been so thoroughly dealt with. The kind of oil employed in the present experiments was the ordinary mineral lubricating oil used in Messrs. Simpson's works.

(Mr. Beauchamp Tower.)

With regard to Professor Kennedy's view (page 123) about a bearing of this kind wearing more towards the circumference, and so causing the pressure to become greater towards the centre, his own notion was that, when the bearing was in thorough working order, there was really no metallic wear at all. As long as there was metallic contact anywhere, the metal was worn away there until it allowed oil to get in between; and the ultimate result was that a space equal to the thickness of the oil film really existed all over the rubbing surface; and as soon as this was the case, there might perfectly well be a uniform pressure in that way all over the surface. The question raised by Professor Kennedy (page 122), as to whether two-thirds was the proper radius to adopt for the centre of pressure, was a matter of opinion to some extent, rather than of fact. It was easy to alter the calculations if another radius were preferred.

As to the diagram, Fig. 7, Plate 32, the curves there shown did actually pass through the points which were recorded. The pressures were taken with uniform increments of load, and the curves were drawn through the actual points plotted, which could readily be added on the diagram to show where the recorded results were. By the inch-pounds (page 125) in which the friction was stated were meant inch-pounds of moment, and not inch-pounds of energy; it was meant that the figures given represented the leverage or moment of the friction taken at the radius of one inch.

The fact that a bearing of this kind, when working at a slow speed, did not act as a pump so efficiently, would no doubt make it necessary to force the lubrication with an ordinary pump, if heavy loads were to be carried at slow speeds.

With regard to not having any lubricating groove at all, but simply an oil hole in the centre of the bearing (page 126), he thought that plan would not answer with a footstep bearing, because the result might be to get a perfectly oil-tight fit round the hole, and not get any oil into the bearing at all. It appeared to him that the radial or diametrical groove was absolutely essential to distribute the oil.

As to the length of time which it was necessary to run a bearing of this kind before it gave reliable results (page 127), the apparatus

described in the report had been kept working for something like five weeks, and had greatly tried the patience of all concerned. Even for days together it was found impracticable to get any satisfactory results; when all seemed to be going on right, some discrepant result would show that the bearing was not working as it should do, and it gave a vast amount of trouble. It had taken a great deal of patience and perseverance to get the few results recorded in the report. That was one reason why a greater variety of bearings had not been tried.

A hard steel hemispherical footstep resting upon the flat hard steel plate (page 127) was a bearing which had been tried in one of the experiments; but the results were so incongruous and unsatisfactory that they had not been recorded. Where the hemisphere touched the flat plate, the hard steel simply wore away, became grooved, and seized.

The suggestion had been made (page 128) that when the bearing seized it was because its pumping action had failed. The fact was however that the pumping action of the bearing never failed; but when the bearing seized it was because the weight was too great, and it seized in spite of the pumping action. The oil flow never ceased at all; and it could always be known how the bearing was going on by seeing whether the oil dropping from the overflow pipe into the lubricating pipe was clean. If the oil was perfectly clean, the bearing was known to be working well; but the earliest sign of seizing was shown by particles of brass in the oil, which could be observed quite well by taking a drop of oil between the fingers, when it could be seen that it was dirty.

The importance of good workmanship had been spoken of by Mr. Walker (page 129). There was no doubt that a bearing must be made perfectly accurate as a fit; and if it was not made so at first, it would have to make itself so by wear, if it was to work satisfactorily. A bearing when in perfect working order was necessarily a perfect fit.

In reply to Mr. Dolby's enquiry (page 131) as to whether there was any change of shape in the rubbing surfaces, due to wear, he should say there certainly was not. The surfaces had been got up flat most carefully. One reason for trying flat surfaces in preference

(Mr. Beauchamp Tower.)

to any other was that they were capable of being more exactly got up to a true surface than any other shape. The surfaces were scraped up, and after they had been running for some time there were still one or two points left where the remains of the scraping could just be seen, showing that there really was practically very little wear indeed and very little alteration of shape. Most of the surface was just skimmed over by the wear, and that was all, just enough to remove the marks of scraping; while here and there a spot would be seen where the mark of the scraping was still left.

Mr. CHARLES COCHRANE, Past-President, asked whether the friction of the hard steel conical point in the centre pop on the top of the plunger did not constitute a minus quantity to be deducted in recording the actual pull on the spring-balance. Had not the friction of that centre to be overcome before the friction of the footstep bearing could be recorded by the spring-balance?

Mr. TOWER replied that the friction of the conical point in the centre pop would of course tend to prevent the record of the spring-balance being correct; and therefore as a matter of fact in reading the spring-balance the precaution had been taken to move the circular plate L, Figs. 4 and 5, Plate 31, first one way by hand, and let it come back, and read the reading; and then to move it the other way by hand, and let it come back, and read the reading again; and the mean between the two readings gave the true record. The effect of the friction was very small indeed, and in that way it was completely obliterated.

Mr. J. HARTLEY WICKSTEED enquired whether the ram of the oil press did not revolve in its cylinder with the oscillations of the spring-balance and the circular plate. Or was it to be understood that the hard steel conical point below the bearing revolved in the centre pop on the top of the ram? If the latter, then the case was analogous to that of a lathe-centre; and with a centre pop 5–32nds of an inch diameter there would be a cross sectional area of only 1–50th of a square inch; and as there was a total load of half a

ton upon the footstep when loaded at 160 lbs. per square inch, there would thus be a pressure of 25 tons per square inch on the hard steel cone, notwithstanding which it did not seize in the centre pop.

Mr. Tower replied that the ram did not turn with the oscillations of the spring-balance, though when the machine was designed it had been hoped that it would; but although the friction of the ram was so small, it was yet found to be greater than that of the hard steel centre. The turning motion of the circular plate and cone was of course very slight; the conical centre was not continuously revolving as the bearing was, but underwent only a small reciprocating rotary movement, corresponding with the slight oscillations of the spring-balance.

Mr. J. Hartley Wicksteed asked whether any theoretical explanation could be given of the action of the multiple discs, of which Mr. Tower had spoken (page 132) as having the effect of multiplying the bearing surface in proportion to the number of the loose discs. That appeared to him to be a complete enigma, because he should have thought that the pressure coming upon one disc would equally come upon all; and that, when the pressure had reached a point which would make one pair of discs seize, it would equally make them all seize.

Mr. George Cawley understood the object of inserting loose discs in a footstep bearing was really to reduce the velocity, by each disc running at a differential speed, and so taking up, as it were, a certain amount of the velocity. For instance, with a shaft running at 300 revolutions per minute, and four loose discs, each disc might be supposed to run 75 revolutions faster or slower than its neighbour. But if this were the case, it seemed to him that, as the present experiments showed that the coefficient of friction increased much with a slower speed, there would be much more friction with the discs than if there were no discs at all, provided the velocity of the shaft when there were no discs was not too great. The object of having the discs he presumed would be in order that, in a case where the velocity of

(Mr. George Cawley.)

the shaft was too high, it might by that means be broken up into a number of differential velocities of lower amount.

Mr. TOWER replied that he certainly believed only one pair of discs was rubbing at a time, and that the velocity was not divided up among the discs at all, but that only one pair of discs at a time was doing the whole work, and went on doing it until they began to get a little too warm. The smallest tendency to seize occasioned more friction between the working pair than between some other pair of discs, and then the latter pair of discs took up the work: so that the work was really divided up into a succession of periods of time, and if there were four discs each disc would have only one-fourth of the whole amount of work to do in the day, and they had intervals of rest which gave them time to get cool.

The PRESIDENT said reference had been made by Mr. Wicksteed (page 117) to a former instance given by Mr. Ford Smith of a footstep bearing carrying as much as 455 lbs. per square inch; but he had since had an opportunity himself of ascertaining from Mr. Ford Smith that upon the upright shaft to which he had alluded there were four bevil wheels, one to each floor, and all facing downwards. The consequence was that in their revolution they all had a lifting action upon the shaft, thereby actually relieving the load upon the footstep, and so facilitating its lubrication, and enabling it to carry what otherwise seemed so heavy a load. As to the advantages of loose rings on the necks of drill spindles, their success was altogether a matter of the intermittent pressure upon the drills, and was not due to reduction of friction. If the weight were only kept on long enough, it would be found that first one pair would seize and then another, and the ultimate result would be the same in the stoppage of the drill, except only that it would run somewhat longer before stopping, because the oil would have to be worked out from between so many more surfaces before the lubrication ceased altogether.

In the discussion upon the previous experiments on a collar bearing he had pointed out (Proceedings 1888 page 182) that the experiments had proved conclusively that friction meant non-

lubrication; and if there was no lubrication between two rubbing surfaces they would not practically carry any weight for any length of time. In his own experience as a locomotive engineer, he had invariably found that if the bearings of an engine were in the habit of persistently getting warm there was too much weight on them. The practical limit at which he had arrived was $2\frac{1}{2}$ cwts. per square inch; and if more than this pressure were allowed on the bearings of a locomotive engine, notwithstanding their freedom to wobble about from side to side, they would not run cold. This limit he was glad to find had been amply confirmed by the experiments now made, which showed that the seizing or heating point was somewhere about $2\frac{1}{2}$ cwts. or 280 lbs. per square inch. Whenever he had had an engine which would not run cold, and in which the weights upon the bearings could not be changed, he had put a bigger axle in and had thereby cured the heating directly. In 1870 he had furnished the dimensions for a pair of large winding engines in South Wales, to wind from a deep pit. There were two winding drums, for which however the bearings had been made too small; and the first time he visited the pit he found there was a stream of water running on all the bearings to keep them cool. The defect could not be altered then, and all he could advise was to go on with the water until a new shaft was wanted, and then to stop the pit while it was being put in.

Even when there was ample freedom of movement in a bearing, he considered that $2\frac{1}{2}$ cwts. per square inch was the maximum which could be put upon any journal to run with safety. All the Research Committee's experiments had been tried under the worst conditions, because the bearings could not move as they would do in ordinary working, and thereby get some relief for themselves. The collar bearings of a steamer at sea, if it were not for the slightly undulatory motion of the ship even in smooth water, would be getting hot continually; in fact they would do so even now, were there not always water kept running upon them in order to keep them cool. The screw-shaft of an Atlantic liner transmitting as much as 14,000 horse-power would not run at all, if there were no possible means of relief for the collar thrust-bearings.

(The President.)

In connection with the experiments made by the Committee it had not been any part of their duty to select or recommend a particular form of bearing; and for the present experiments on pivot friction they had simply taken what they considered would be the nearest approach to a perfect fit, namely a flat surface for both the footstep and the bearing. The conduct of these experiments had been a matter of great interest for Mr. Mair-Rumley and for himself, and for Mr. Tower also. The Members he was sure would wish to join him in a cordial vote of thanks to Messrs. Simpson and Co., for their kindness in again providing free accommodation, engine power, assistance, and other facilities for these experiments, and in constructing at net cost price the requisite apparatus; and also to Mr. Tower for the great pains and thought which he had bestowed upon this work, and for his great ingenuity in scheming the machine employed for the experiments. He considered it to be an admirable machine for doing what the Committee had attempted to do.

ON RECENT TRIALS OF ROCK DRILLS.

By Mr. EDWARD H. CARBUTT, Past-President,
and Mr. HENRY DAVEY, of London.

During the summer of 1890 an Exhibition of Mining and Metallurgy was held at the Crystal Palace, Sydenham, the success of which was due in a great measure to the energy of the honorary secretary, Mr. George A. Ferguson. Towards the close, the Council of the Exhibition arranged for a trial of the Rock Drills exhibited, or of as many of them as the makers cared to enter for competition. Seven power drills and two hand drills were entered; and the authors of this paper, having been appointed to superintend the trials and act as judges, thought that the results, together with a description and illustrations of the mechanism of the drills, would form a more or less valuable contribution to the literature of the subject in the Proceedings of this Institution, and might probably give rise to a discussion on the general subject, and elicit some further information to preserve on record.

The drills exhibited were all of the striking or percussive kind, and may be divided broadly into three classes:—(1) drills in which the valve is worked by air pressure; (2) drill shaving the valve worked through mechanical connections by tappets or cams; (3) valveless drills, in which the main piston itself performs the office of valve. In the first of these classes, the piston performs the function of a valve for reversing the actual valve; while the latter in its turn causes the motion of the piston to be reversed. In the second class, the motion of the piston is employed to reverse the valve by knocking it over the ports.

The rules laid down for the competition were settled by the engineer of the Exhibition, Mr. Edward Wilkinson, and were agreed to

by all the competitors, the judges being in no way responsible; they are appended for reference. The drills entered for the competition were the following:—McCulloch's "Rio Tinto"; Stephens' "Climax"; Bickle; Ingersoll-Mayne; Daw; Coles; Hathorn's "Eclipse"; Ingersoll hand-power; and Bromfield-Ingersoll hand-power. All the seven power drills were fed by hand, none being worked with a self-acting feed.

McCulloch's "Rio Tinto" Drill.—In this drill, shown in Figs. 1 to 5, Plates 33 and 34, the two pistons forged solid upon the piston-rod perform the double function of acting themselves as outlet or exhaust valves, and also of actuating the inlet slide-valve V through a tappet T struck by a swelling or spherical boss surrounding the piston-rod midway between them. The compressed-air or steam for working the drill is admitted to the valve-chest, and is distributed by the slide-valve through ordinary ports and passages to the ends of the cylinder alternately. The exhaust takes place direct from the cylinder through two sets of four holes E, Figs. 1 and 5, which are alternately covered and uncovered by the pistons. The further extremities of the admission passages, just where they enter the cylinder, are each fitted with a rectangular mushroom valve I, Figs. 1 and 4, which opens for admission into the cylinder, but closes against exit therefrom. Hence, after the set of four exhaust holes in front of either piston has been closed by the piston itself, the exhaust air remaining in that end of the cylinder is compressed to the end of the stroke, thus forming a cushion, and preventing the piston from striking the cylinder cover. In the forward stroke however, owing to the position of the exhaust holes, the cushioning does not offer any appreciable resistance to the force of the cutting blow, except when the piston is travelling too far, in consequence either of a soft place in the rock, or of the drill not being kept in its proper working position. When the exhaust air is being compressed in either end of the cylinder, it presses the non-return mushroom valve I tighter upon its seating; whereas the corresponding valve at the other end of the cylinder is full open for the admission, the driving air pressure being greatly in excess of the strength of the light spring

that tends to close the non-return valve. This action takes place alternately at each end of the cylinder.

When the inlet slide-valve V has been moved by the tappet to either end of its travel, so as to close one of the admission ports and open the other, it is retained in that position by the air pressure acting upon its admitting end, and any movement is thereby prevented during the time that the boss on the piston-rod is not in contact with the tappet. The slide-valve is cylindrical, and the cylindrical casing or chest in which it slides is provided with an oil hole on the outer side, and on the inner side has a longitudinal slot in which the arm of the tappet moves. At each extremity of its travel the slide-valve is pressed by the tappet against a stop, consisting of a steel disc D with india-rubber backing, Fig. 1. When desired, both the valve and the tappet can be reversed end for end, for equalising their wear.

During the inward or return stroke of the drill, it is caused to rotate through rather less than a quarter of a turn, by means of a rifled spindle S fitted into the back cylinder-cover, and carrying a ratchet wheel R with pauls held up by springs, which allow it to rotate in one direction only, Figs. 1 and 2. On the spindle works a corresponding bush, fitted in the back end of the piston-rod, in which is also made a cavity long enough to receive the spindle when the piston-rod is at the extremity of its inward stroke. When the drill is making its forward or cutting stroke, the ratchet wheel and rifled spindle are rotated freely by the bush in the piston-rod; while in the return stroke they are held by the pauls from rotating, and consequently the drill is now rotated by the bush through the extent of the turn provided in the rifling of the spindle.

The drill cylinder is cast with V shaped projections, sliding in corresponding grooves in the cradle C in which it is mounted, Figs. 3 to 5. The feed is given by a screw worked by hand. The cylinder is 3½ inches diameter with a stroke of 5 inches; and the weight of the drill unmounted is 308 lbs.

In Figs. 35 and 36, Plate 12, is shown the quarry bar, on which the drill is mounted for certain kinds of work.

Stephens' "*Climax*" *Drill.*—In the construction of this drill, shown in Figs. 6 to 12, Plates 35 and 36, one of the principal features is the reversible tappet-valve V, Fig. 11, which is a flat plate rocking on a centre pin, and actuated by a spherical boss on the piston-rod, midway between the two pistons. The valve contains a pair of admission ports A; and a pair of recesses or exhaust ports E, which control two corresponding pairs of ports in the valve-chest face, communicating with the ends of the cylinder and with the atmosphere, Figs. 7 to 9. On the back of the valve is another pair of recesses or exhaust ports, corresponding with those on the face, so that when worn the valve can be reversed back and face, and upside down; it is then practically as good as a new valve and new tappet.

A second feature is the twisting or rotating device on the rifled spindle in the back end of the cylinder, which consists of a crown ratchet clutch R, Fig. 6, whereby the use of pauls is dispensed with. The strain which would come upon a single paul and tooth for rotating the drill, or upon a pair, is here distributed equally over fifteen catches, which all act at the same time, the sliding half of the clutch being all in one piece, and pressed forwards against the rotating half by a single spring. This arrangement admits of the clutch being from 1 inch to 1½ inch larger in diameter than a ratchet wheel in the same cylinder cover, because no space is required for pauls and springs outside the circumference of the ratchet. The strain therefore, besides being distributed over a much larger number of teeth, is also removed to a greater distance from the centre.

Another feature is the insertion of loose adjusting liners L in the cradle C, Fig. 7, which are so arranged that any movement of the cylinder in the cradle can be readily adjusted in a few minutes by these loose liners; and provision is made for them in the construction of the cradle. The feed is given by a screw worked by hand.

A 3-inch drill unmounted weighs about 240 lbs., and a 3½-inch about 280 lbs.

Bickle Drill.—This drill, shown in Figs. 13 to 16, Plate 37, belongs to the class of machines in which the valve is worked by

air pressure. The valve V is made in one piece, in the form of a small double piston with two wide annular grooves turned in it for the passage of air to and from the main cylinder; it has a travel of only about an inch inside its cylindrical chest, for covering and uncovering the air ports in the main cylinder. The travel is produced by means of the main piston, which has a wide annular recess turned in it midway between its two ends. The piston covers and uncovers alternately two small exhaust ports leading from the ends of the valve-chest. When either of these ports is uncovered by the annular recess in the main piston, the air at that end of the valve-chest exhausts, and the air pressure acting on the opposite end of the piston-valve shoots it into its proper position for admitting air pressure into the drill cylinder.

In order to prevent the great wear and tear of the cradle, consequent upon continuous use, it is armoured with two light rubbing bars of steel of angular section, which extend the whole length of the cradle and are secured thereto by bolts passing through oblong holes in the cradle; they are adjusted by means of four bolts, which are tightened up for drawing them together when necessary. These wearing pieces can be renewed at any time.

The design of this drill lends itself readily to the construction of a light machine. The $3\frac{1}{2}$-inch drill unmounted weighs about 280 lbs.

Ingersoll-Mayne Drill.—In this drill, Figs. 17 to 21, Plate 38, made by Messrs. Le Gros, Mayne, Leaver and Co., a positive motion is retained for the valve, while at the same time all moving parts between the piston and the valve are done away with. As shown in Fig. 18, the valve V itself is placed in direct contact with the piston, by which it is actuated. Midway in the length of the piston is a wide annular recess having a gentle inclined plane at each end. The intervening annular space round the middle of the piston forms the chamber into which the steam or air is first admitted. The valve V is over this middle portion, and is in the form of a segment of a circle, fitting accurately against a cylindrical face in the valve-chest, the axis of

this face being at right angles to that of the drill cylinder. In the outer face of the valve is provided a pair of recesses properly proportioned for admitting the air past the valve to the ends of the cylinder alternately. The air being admitted into the middle chamber of the cylinder through the inlet I, Fig. 21, presses the valve outwards and close up against its cylindrical face; and the piston being at one end of its stroke, the other end of the valve has been raised by the inclined plane, and the valve has been rotated over its curved face, to a sufficient extent to open the port for the admission of the air to the end of the cylinder. The piston is thereby caused to make its stroke, and in so doing it reverses the valve by means of the other inclined plane. At the same time that the admission is taking place to one end of the cylinder, the opposite end is open to the exhaust E through the other recess in the back of the valve. It will thus be seen that the only moving pieces are the piston and the valve.

For better securing the drilling tool to the piston-rod, as shown in Figs. 19 and 20, a socket adapted to the shank S of the tool is bored in the enlarged head H, which is forged solid on the end of the piston-rod; and the shank is firmly gripped in the socket by a chucking block B, tightened by a U shaped staple or clamping bolt C.

As the piston, piston-rod, and tool-holder are all one forging, the front cylinder-cover has to be made in two parts, which must be so put together as to be air-tight and to receive the packing gland. As shown in Figs. 17 and 18, the front cover is made in two halves to fit the cylinder, and has a conical prolongation, round which is fitted a conical steel ring R. The smaller end of the ring is large enough to let the piston pass through it for insertion into the cylinder; and the ring has ears on opposite sides, for tie bolts securing it to the cover at the back end of the cylinder. This method of fixing the back and front cylinder-covers by tie bolts forms a further security against injury, in addition to the buffer rings which are inserted in the ends of the cylinder to protect the covers. The front cover is bored out to form a stuffing-box, into which the gland is screwed in two halves.

The rotation of the drill is provided for by means of a rifled bar and a ratchet wheel having double spring pauls, the latter protected by being placed within the back cylinder-cover. The drill cylinder is 3 inches diameter and 6 inches stroke, and the weight of the machine unmounted is 230 lbs.

Daw Drill.—In this drill a simple piston-rod, having an ordinary piston-head, is caused to reciprocate by a slide-valve worked by the air-pressure. A drill 3 inches diameter with 5 inches stroke is only 20 inches long; and when mounted on a cradle to give a feed of 20 inches, it weighs with the cradle less than 190 lbs. In the working of rock drills in which the valve is moved by the air pressure, trouble is often caused when fixing the drill, by the valve dropping into its central position, thereby cutting off all air-supply to the cylinder. When such a thing occurs with this drill, the valve can be pushed off the centre by a small bar, and then the drill goes to work automatically.

Coles Drill.—In Figs. 22 to 25, Plate 39, is shown one of these drills having a cylinder $2\frac{1}{2}$ inches diameter, in which the working stroke of the piston is about 4 inches. The valve is worked automatically by the air pressure. The feed is by hand. The drill is caused to rotate by means of a steel twist-bar, which works in a phosphor-bronze nut fitted in the back end of the piston; a ratchet wheel with pauls is attached to the twist-bar, for ensuring rotation in one direction only. The end of the piston-rod is bored with a conical hole to receive the drill bit, and is strengthened by a steel collar fitted round it; a cotter hole is provided for driving the drill out. The front cylinder-cover through which the piston-rod passes has a deep annular groove turned in it to receive the packing, which is introduced through a long nozzle N projecting at one side, Fig. 23. The nozzle is fitted with a set-screw which forces the packing against the piston-rod. The advantage claimed for this form of stuffing-box is that there is no loose gland to drop out and damage the machine.

The principal distinguishing feature of the drill is its valve and valve-box, which are fitted on the side of the cylinder, as shown in

Figs. 22 and 24. The valve V, Fig. 25, is hollow, and perfectly cylindrical both inside and out, its axis being at right angles to that of the drill cylinder; the inlet ports are formed through the sides of the valve, and it is reduced in the centre for allowing the exhaust to pass round the outside. The valve-box has five passages for the supply and exhaust of air, which form concentric rings having parallel sides. The compressed air passes into the inside of the valve from one or other of the two outer passages; and thence into the drill cylinder through either of the two adjacent passages, according to which end of the cylinder it is to enter. The exhaust takes place through the centre passage. From each extremity of the valve-box a small port communicates with the drill cylinder, for exhausting the air alternately from either end of the valve-box and thereby enabling the valve to be actuated by the pressure on the other end. Both the valve and the valve-box are made of No. 7 alloy of phosphor-bronze, this metal being found the most suitable for strength, lightness, and evenness of texture.

The advantage claimed for this construction of valve and valve-box is that their cylindrical form allows of excellence in manufacture. The valve being perfectly cylindrical, symmetrical in shape, and uniform in thickness, can be turned exactly parallel and true; and the valve-box, having its passages constructed to form parallel concentric grooves uniform in shape all round, can be bored exactly parallel and true by means of a double-ended cutter, to a perfection impossible where there are ports in one side of its cylindrical surface and not in the other. On this account the valve can be made to fit the valve-box with great accuracy. The supplementary exhaust ports through the body of the drill cylinder for actuating the valve are drilled through it after the cylinder has been bored out, so as not to interfere with the perfect evenness of the bore. The action of the valve is very simple. A little air is always leaking round the valve and accumulating in each end of the valve-box beyond the valve. The supplementary exhaust ports from the ends of the valve-box enter the drill cylinder at a short distance fore and aft of the middle of its length, Fig. 22, and each in the same transverse section as another port which is permanently open to the exhaust.

Each pair of the fore and aft ports is covered by the body of the piston during the greater part of its stroke, whereby any communication between the two ports in each pair is prevented; but when the piston is nearing either end of its stroke, a wide annular groove turned in the opposite end of its length forms a communication between the corresponding pair of ports, thus allowing the air to exhaust from one end of the valve-box; and as the other end is under pressure, the valve at once flies over and reverses the motion of the drill piston. The drill unmounted weighs 168 lbs.

Hathorn's "Eclipse" Drill.—In this drill, shown in Figs. 26 to 28, Plate 40, the valve is worked by the air pressure, and its reversal is effected by the drill piston, which performs the function of a D slide-valve for the purpose. The valve is itself a D valve sliding on a cylindrical face, and having on each end a piston cast in one piece with it. The air pressure is admitted into the annular space between the two valve-pistons and on the back of the valve. The drill piston is more properly a pair of pistons, with a long annular groove or recess between them, which is open to the exhaust; the motion of the piston causes the recess to uncover alternately two small ports, which communicate crosswise with the extremities of the valve-chest, that is, the bottom port with the top end and the top port with the bottom end of the valve-chest. Thus when the drill piston is nearing the top end of the cylinder, the bottom end of the valve-chest is open to the exhaust through the upper small port; and the lower small port being at that time covered by the body of the drill piston, the valve is reversed by the air pressure leaking past the upper valve-piston into the closed space behind it, while the leakage past the lower piston is free to escape to the exhaust. The air pressure being thus admitted upon the top of the drill-piston through the upper main port produces the downward or outward stroke of the drill, giving the blow. The reversal of the valve for the backward or return stroke takes place in exactly the same way. The rotation of the drill in the return stroke is effected in the usual manner by means of a ratchet wheel and rifled bar. The drill cylinder is 3 inches diameter and 4½ inches stroke; and the weight of the machine unmounted is 264 lbs.

Ingersoll Hand-Power Drill.—This consists of a strong cast-iron cylinder, shown in Figs. 29 to 34, Plates 41 and 42, in which works a steel rod R in place of a piston-rod, carrying the drilling tool at its outer extremity by means of a suitable clip. Across the cylinder at about midway in its length is fixed a shaft, carrying two flywheels W with handles, and two hardened steel cams C, each of which has three points, Fig. 31, thereby producing three blows at each revolution. As the cams revolve they alternately lift and release a steel cross-head H, which is fixed by a collar on the working rod R and projects on each side of the cylinder, and is surmounted by a strong volute spring enclosed in the cylinder. The spring is compressed by the lifting of the cross-head, and its recoil on release produces the blow, which is delivered dead on the stone without shock to the men. The spring ordinarily supplied for a drill to be worked by two men is compressed to 200 lbs., and produces with the momentum of the working rod and drill a blow of about 300 lbs. Springs of different powers however are easily inserted, enabling the machine to be adjusted to the strength of the men working it. From 60 to 100 revolutions of the flywheels can be made per minute, producing three times that number of blows; and by an electric motor as many as 120 revolutions per minute can be made. The rotation of the drill is provided for by a ratchet wheel with oblique teeth fixed on the working rod, Figs. 32 and 33, into which engages a long oblique spring-blade or feather-paul P, shown dotted in Fig. 34, fixed in the thickness of the cylinder, whereby a partial turn is produced in the backward stroke; while in the forward stroke the rod goes free, without any impediment to the blow. The turning mechanism being contained within the cylinder is protected from dirt and grit.

The automatic feed is effected by the tail end of the working rod, which projects through the back cylinder-cover, and is tapered off in a cone at its extremity, Figs. 29 and 30. As the work progresses, this cone gradually comes within the cover, and permits the inward movement of a small radial lever L, to which is jointed a paul that works into a ratchet-wheel nut running on the feed-screw. In the backward stroke of the working rod, its thicker part below the cone pushes the lever outwards, whereby the paul is thrust into

the ratchet, thus giving it a turn on the screw and feeding the machine forwards. This feed adapts itself exactly to the rate of penetration. It can be thrown out of gear when desired.

The length of the stroke is $3\frac{3}{8}$ inches, and the weight of the machine is 300 lbs.

Bromfield-Ingersoll Hand-Power Drill. — The distinguishing feature of this drill is that no weights are necessary. The recoil is taken up by a compensating-lever mechanism, which causes the blow to be delivered with an increasing velocity, at any angle of work.

Trials.—The drills above described, with one or two others, were subjected to a competitive trial at the Mining Exhibition in October last; and the Tables appended give the results obtained. These results will be better understood in connection with the following extract from the judges' official report on the trials:—

"We thought it expedient that, as a standard of comparison with the hand-power drills, a hole should be bored with mallets and chisels, two men striking and one holding the chisel. This was done on the 11th of October, after the conclusion of the power-drill trials. All the trials were made on a block of granite, 8 feet by 6 feet and 22 inches deep, firmly fixed on a bed of concrete.

"The air-power drills were supplied with compressed air at a pressure of from 60 lbs. to 70 lbs. per square inch, commencing always at 70 lbs. or as near that pressure as was possible; and in no case did a trial begin at more than 72 lbs., or finish at less than 62 lbs. The average pressure in all the trials varied only from 65 to $68\frac{1}{4}$ lbs. The pressure was recorded every half minute. A meter was placed on the pipe leading from the air receiver to the drill. The pipe was 2 inches diameter up to a few feet past the meter; and to the end of this pipe the drill supply-pipe was coupled. The following Table 1 is a record of observations taken during the trials. It was evident that the meter, although apparently working well when as much as 20 cubic feet of air was passing per minute, could not be relied upon for smaller quantities; and accordingly a test of the meter was made by Mr. Davey on the 11th of October,

after the trials, and it was found, as anticipated, that for small quantities of air it was not correct; but for the quantities recorded in the tables of results the readings might be taken as relatively correct.

"It is important to observe that the drills which did the greatest quantity of work in the given time did also the greatest quantity of work per cubic foot of air used, as far as could be ascertained; this is seen from Tables 2 and 3."

Air Meter.—This was lent by Messrs. J. Tylor and Sons, and was in fact one of their inferential water meters described at a former meeting (Proceedings 1882, page 41), applied in this case to the measurement of air instead of water. It is shown in horizontal and vertical sections in Figs. 37 and 38, Plate 43. In its passage through this meter it will be seen that the air is never brought to rest, and receives no check in its flow from inlet to outlet; it simply turns a fan F connected with a counter N. After passing through a fine strainer for freeing it from dust, the inlet air enters through two oblique slots S in the fan-case C, which direct it upon the fan-blades almost tangentially to the circle of their revolution. After striking the blades it rises, and passes out through openings above the fan, on its way to the outlet. The tips of the blades revolve so close to the fan-case that no current can escape past them. Moreover on the inside of the case are cast vertical corrugations or slight ribs at frequent intervals; these form vortex chambers, which act as brakes, and ensure accuracy of registration throughout a wide range of speed; they also bring the fan to rest directly the flow ceases. Between the upper side of the fan and the top of the fan-case a considerable space is left, in which are arranged a number of radial ribs with horizontal projecting ledges L. By these a portion of the outgoing air is deflected back upon the fan blades, to a greater extent as the velocity of the flow increases; and this arrangement has proved most valuable in rendering the meter accurate both at high and at low velocities. The fan is made of phosphor-bronze, and is carefully balanced; the blades are twisted in opposite directions alternately, so as to avoid thrust either upwards

or downwards. It runs on a pivot, which rises from the base of the fan-case, and enters a hole in the fan-boss; the top of the hole is jewelled to bear on the top of the pivot. The joint between the outside of the fan-case and the outer casing surrounding it is made air-tight with an india-rubber washer I. The connection between the fan-spindle and the counter N is through worm gearing, which works with little friction.

General Observations.—The principle of machines for rock drilling is that which has from time immemorial been all along recognised in hand-drilling; namely a succession of blows given to a chisel, which is partially rotated between each blow. In hand-drilling, the chisel is held in position and rotated by one man, whilst another strikes the blow after the partial rotation of the chisel by the man who holds it. There is also the method of drilling by means of what is called a jumper, that is, a long heavy bar with chisel end, which is jumped up and down in the hole by one man who also rotates it. It is clear that after a blow has been given the chisel must be raised before it can be rotated. In machine drills it became mechanically simple to effect the double operation of raising the chisel and rotating it, by attaching the chisel to the hammer and providing the latter with means of rotation.

In hand-drilling, the blow is what may be termed a dead blow; that is, no part of the blow is taken up by any spring or cushion between the hammer and its work. In those machine drills in which the hammer is its own valve, the air for effecting the return stroke is admitted in front of the hammer before the blow is actually struck; and in the other machines in which the air is admitted through a subsidiary valve, there is the same action when the valve is worked by a tappet, although when it is moved by air the inertia of the valve tends to modify the effect, by delaying the moment of admission of air for the return stroke. It is clear therefore that machine drilling is possible with quick strokes only, so quick that either the momentum of the hammer shall overcome the air resistance at the moment of striking the blow, or that the blow shall be struck before the air is admitted in front of the hammer, the admission having been

retarded by the inertia of the valve. With the original Nasmyth steam-hammer a dead blow was produced by means of a small kicker or weighted lever, centred on the face of the hammer head and held up by a spring. At the instant of striking the blow, the momentum of the weighted lever compressed the spring, and the kicker or tail of the lever communicated its motion to the steam valve, which thereupon admitted steam for lifting the hammer again. This principle does not appear to have been made use of in rock-drilling machines, probably for good reasons; but the example serves to illustrate the nature of the difference between a dead blow and that commonly given by these machines.

Turning to the actual results of the work done by the rock-drilling machines which were tried, it is difficult to form any broad and general conclusions as to the efficiency of the different drills, as this may be connected with variations in the principles and details of the valve mechanism employed. What really does appear is that the important points are purely of a practical nature; and the following may be profitably discussed :—mechanical details; certainty of action; weight of mechanism in relation to durability and portability.

The mechanical details have already been described, and are illustrated by the drawings and machines exhibited. In certainty of action it did not appear at the trials that there was any practical difference between the valves moved by air and those worked by tappet.

As regards weight of machine for a given size, it is of course desirable to have it as light as possible, for the sake of portability; but considering the rough usage to which a rock drill must necessarily be subjected, strength of parts is still more important. In the trials the large and therefore heavy machines were those which did the best work, namely those with $3\frac{1}{2}$-inch cylinder, weighing from 280 to 308 lbs. each (Table 4). The 3-inch machines, weighing from 190 to 264 lbs., did good work. There was only one $2\frac{1}{2}$-inch machine tried, but its full capabilities were unfortunately not properly tested, because the air was throttled at the inlet cock. Small and therefore light machines are no doubt required, and are serviceable for certain

classes of work; but for quarry work the larger machines would appear to be superior. The stability of the machines which were tried on the quarry-bar, Figs. 35 and 36, Plate 42, was added to by the fact that there were always four drills on the bar during the trials, while only one was at work at a time; but in the tripod trials each drill was provided with its own tripod without any additional weights whatever. In all the trials the holes were vertical, or as nearly so as practicable.

As was pointed out in the judges' report, the failures which occurred in some of the trials might or might not have resulted from defects in the machines. Where the cause of failure could be seen, it has been noted with the rest of the results in Table 1; and in Tables 2, 3, and 4, the mean results are summarised, and the sizes and weights of the machines are given.

From the particulars of the work done by the hand-power machines, it does not appear that these are equal in efficiency to the hand-hammer in drilling vertical holes. The first machine with two men drilled a $1\frac{1}{4}$-inch hole 12·37 inches deep, having a capacity of 16·69 cubic inches, in 17 minutes; whilst three men by hand, two striking and one holding the chisel, drilled a somewhat larger hole 22 inches deep, having a capacity of 27·64 cubic inches, in $18\frac{1}{2}$ minutes. In this comparison no allowance is made for the labour of moving and fixing the machine.

In conclusion the authors wish to express their thanks to the various competitors who have so kindly supplied drawings and information for enabling this paper to be compiled.

TABLE 1 (*continued on opposite page*).

Trials of Rock Drills, 7th and 9th October 1890.

Name of Drill.	No. of hole.	Form of cutting edge of drill.	Diam. of Cyl. Inches.	Diameter of Drill. At start. Inch.	Diameter of Drill. At finish. Inch.	Size of Hole. Depth. Inches.	Size of Hole. Volume. Cubic Inches.
Power Drills driven with Compressed Air. Drills mounted on a Bar.							
Coles	1	–	$2\frac{1}{2}$	1·25	1·19	4·31	6·04
	10	–		1·25	1·19	7·75	10·59
Daw	2	–	3	1·50	1·37	12·37	21·94
	11	–		1·50	1·31	13·06	22·46
Climax	3	–	$3\frac{1}{2}$	1·75	1·69	3·06	7·77
	9	–		1·75	1·69	11·50	29·37
Bickle	4	–	$3\frac{1}{2}$	1·81	1·75	8·00	21·25
	8	–		1·81	1·72	18·06	48·03
Ingersoll-Mayne	5	+	3	1·53	broken	4·50	7·77
	6	+		1·53	broken	10·87	18·42
Eclipse	7	–	3	1·53	1·50	12·62	25·92
	16	–		1·53	1·50	13·87	26·78
Rio Tinto	12	–	$3\frac{1}{2}$	1·81	1·75	13·94	37·15
	17	–		1·81	1·75	15·50	42·85
Power Drills driven with Compressed Air. Drills on Tripods.							
Ingersoll-Mayne	13	+	3	1·56	1·53	4·00	8·64
	19	+		1·56	1·53	4·56	9·93
Eclipse	14	–	3	1·50	1·47	16·06	30·75
	18	–		1·50	1·44	14·50	27·21
Rio Tinto	15	–	$3\frac{1}{2}$	1·87	1·81	13·94	39·96
	20	–		1·81	1·78	14·56	41·47
Hand-Power Drills.							
Bromfield-Ingersoll worked by two men	–			1·25	1·19	12·37	16·69
Ingersoll worked by two men	–			1·25	1·19	11·06	14·03
Hole bored by Hand, two men striking and one holding chisel.							
Handwork by three men, 11th October 1890.	–			1·37	1·25	22·00	27·64
	–			1·25	1·06		

(*concluded from opposite page*) TABLE 1.

Trials of Rock Drills, 7th and 9th October 1890.

No. of hole.	Actual Working Time. Seconds.	Air used. Total Volume. Cubic Feet.	Air used. Average Pressure. Lbs. per sq. inch.	Remarks.
Time allowed, Two minutes each hole.				
1	120	–	65¾	Good run; no hitch.
10	127	–	67½	Do. do. [drill ran out of guide.
2	100	40	65½	Good run; drill struck once with hammer;
11	120	44	67¼	Good run; drill struck once with hammer.
3	100	41	65½	Drill dropped out; stopped for 20 seconds.
9	120	46	65¾	Good run; no hitch. [stop.
4	60	25	61¼	Flexible air-pipe fouled and broke, causing
8	120	59	65	Good run; no hitch.
5	30	–	67¾	Machine stuck; drill broken.
6	95	31	68½	Machine stuck and drill splintered after [working 95 seconds.
7	120	45	67½	Good run; no hitch.
16	120	35	68¼	Do. do.
12	120	62½	67¼	Good run; no hitch.
17	120	59	66½	Do. do.
Time allowed, Two minutes each hole.				
13	120	12½	66¼	Machine would not work regularly.
19	120	–	64¾	Do. do.
14	120	46	66	Good run; no hitch.
18	120	46	66	Do. do.
15	120	62½	67½	Good run; no hitch.
20	120	60	64½	Do. do.
Time allowed, Twenty minutes each hole.				
Minutes 17				Revs. per min., taken at intervals, 116, 86, 100. Stopped 1½ min. at end of 14 mins. for another drill; ceased work at end of 18½ mins.
Minutes 10				Revs. per min., taken at intervals, 80, 68, 86. Stopped 3½ mins. at end of 9½ mins. for another drill; worked for 1½ min.; then ceased because drill was not true with hole.
Time allowed, Twenty minutes.				
Minutes 18½				Two drills used. One first-class man, two not very practised.

TABLE 2.

Mean Results of Drilling the Two Holes in Table 1 *in time allowed of Two minutes each.*

Name of Drill.	Drill on Bar or on Tripod.	Depth drilled.		Volume drilled.		Air used per minute.	Granite bored per cub. foot of Air.
		Total.	Per minute.	Total.	Per minute.		
		Ins.	Ins.	Cub. Ins.	Cub. Ins.	Cub. Ft.	Cub. Inch.
Rio Tinto	Bar	29·43	7·35	80·00	20·00	30·4	0·658
	Tripod	28·50	7·12	81·43	20·35	30·7	0·664
Bickle .	Bar	26·06	6·51	69·28	17·32	21·0	0·824
Eclipse .	Bar	26·50	6·62	52·70	13·17	20·0	0·658
	Tripod	30·56	7·64	57·96	14·49	23·0	0·630
Daw . .	Bar	25·43	6·35	44·40	11·10	20·6	0·538
Climax .	Bar	14·56	3·64	37·14	9·28	21·8	0·426
Ingersoll-Mayne .	Bar	15·37	3·84	26·19	6·54	—	—
	Tripod	8·56	2·14	18·57	4·64	—	—
Coles . .	Bar	12·06	3·01	16·63	4·15	—	—

TABLE 3.

Results of Drilling the best of the Two Holes in Table 1.

Name of Drill.	Drill on Bar or on Tripod.	Depth drilled.		Volume drilled.		Air used per minute.	Granite bored per cub. foot of Air.
		Total.	Per minute.	Total.	Per minute.		
		Ins.	Ins.	Cub. Ins.	Cub. Ins.	Cub. Ft.	Cub. Inch.
Bickle .	Bar	18·06	9·03	48·03	24·01	29·5	0·814
Rio Tinto	Bar	15·50	7·75	42·85	21·42	29·5	0·726
	Tripod	14·56	7·28	41·47	20·73	30·0	0·691
Eclipse .	Bar	13·87	6·93	26·78	13·39	17·5	0·765
	Tripod	16·06	8·03	30·75	15·37	23·0	0·668
Climax .	Bar	11·50	5·75	29·37	14·68	23·0	0·638
Daw . .	Bar	13·06	6·53	22·46	11·23	22·0	0·510
Ingersoll-Mayne .	Bar	10 87	5·43	18·42	9·21	15·5	0·573
	Tripod	4·56	2·28	9·93	4·96	—	—
Coles . .	Bar	7·75	3·87	10·59	5·29	—	—

TABLE 4.

Sizes and Weights of Drills; and Valve motion.

Name of Drill.	Diameter of Cylinder.	Length of Stroke.	Weight of Machine.	Valve moved by
	Inches.	Inches.	Lbs.	
Rio Tinto . . .	$3\frac{1}{2}$	5	308*	Tappet
Climax	$3\frac{1}{2}$	5	280*	Tappet
Bickle	$3\frac{1}{2}$	5	280*	Air
Ingersoll-Mayne . .	3	6	230*	Tappet
Daw	3	5	190*	Air
Coles	$2\frac{1}{2}$	4	168*	Air
Eclipse	3	$4\frac{1}{2}$	264*	Air
Ingersoll Hand-power . .	–	$3\frac{3}{8}$	300	–
Bromfield-Ingersoll Hand-power . .	–	–	–	–

* With cradle, but unmounted.

Rules for Rock Drill Competition.

1.—Competitors shall mount their machines on a bar 4 inches diameter, provided for the purpose.

2.—Each machine shall bore two holes in a granite block, one hole on each side of a centre line which will be marked on the block, the holes being numbered 1, 2, 3, 4, &c. The number of hole which each machine will have to bore will be balloted for.

3.—The man in charge of each machine will be required to remove the cylinder-end of his machine, for enabling the judges to measure the diameter of cylinder before competition. The drills will also be measured before boring commences, and also after finish of hole.

4.—Each machine will be required to bore a hole of a diameter equal to half the diameter of its cylinder.

5.—After the boring, the cubic quantity cut will be measured by pouring water into the hole, or by such other means as the judges may think best.

6.—The air used by each machine will be measured by a meter fixed on the main for the purpose, and will be supplied as nearly as practicable at 60 lbs. pressure per square inch.

7.—Two minutes will be allowed for each drill to bore one hole, the judges giving the time for starting and finishing. No change of bit will be allowed after starting.

8.—The granite block which is operated upon will be railed in, and no one will be allowed within the railing except the judges, the engineer of the exhibition, and two men for working the drill at the time of competition. All others, competitors included, must keep outside the fence.

9.—In order that every one may have an equal chance in starting his hole, the stone will be faced where the holes are to be bored.

10.—Each competitor may use whatever shape of bit he considers best.

11.—A competition will also take place on tripods, the same rules applying as regards size of drill &c. No weights will be allowed except ordinary weights on legs.

12.—Any infraction of the above rules will disqualify the competitor during the whole period of the competition.

13.—The decision of the judges will be absolutely final on all points.

Discussion.

Specimens were exhibited of McCulloch's "Rio Tinto" drill, the Bickle and Coles drills, and Hathorn's "Eclipse" drill; and also of the bits or chisels used with them. A specimen was also shown of the inferential water meter used as an air meter, which was taken to pieces for examination of the internal fan-case and revolving fan.

Mr. Edward H. Carbutt, Past-President, thought the Exhibition of Mining and Metallurgy at Sydenham, at which these rock drill trials had taken place, was one of the best exhibitions there had been of its kind. It was a pity that it had not been held in a more central place in London; for as it was, he believed comparatively few people had seen it. Every one who did see it must have been delighted with it, for he supposed it was one of the finest exhibitions of metallurgy that had been held in this country. All the colonies seemed to have vied with one another to make it a success; and every one who saw what they had produced must have been pleased with the efforts they had made in developing their mineral resources. The exhibition included mining machinery as well as metallurgy; and some of the exhibitors of rock drills agreed that they would have a competitive trial of their machines. At the Royal Agricultural Society's shows, as was well known, trials of engines and machinery had been held for many years; and there was no doubt that they had conferred great benefit on the makers of agricultural machinery, who in that way found out what their faults were, and went on improving from year to year. The drill trial at Sydenham he believed was the first of its kind of any consequence that had taken place in this country; and therefore it could not be considered as entirely perfect, because every one was excited and anxious to do his best, and occasionally little slips occurred, which perhaps would not have occurred if the trials had taken place every year. In one case, as mentioned in Table 1, the flexible air-pipe had got fouled and had broken; and that stopped the trial, and naturally put the drill to a certain extent at a disadvantage. Taking it all in all however, and considering that it was the first trial of the kind, he thought all the exhibitors must have been well satisfied with the way in which it was carried out. As far as he knew, both Mr. Davey and himself had been careful to note everything that took place; and he believed everything had been done in the fairest possible way. They could not, even if they wished, say which was the best drill of those tried, because one might be best for one purpose and another for another. But he thought what had been found out was that there were good points in almost every drill. For his own

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part as an old steam-hammer maker, he was delighted to find that, the action of the drills being a steam-hammer action, engineers had been able to make rock drills which with so little material could do such a large amount of work. Every one who used rock drills must be well satisfied that engineers had put forth their best efforts in trying to make rock drills as perfect as they could; and the exhibitors were to be complimented on the skill with which they had overcome the difficulties so far. No doubt there were other difficulties still in the way, and he believed these trials would have a good effect in the future, and that further endeavours would still be made to do the largest amount of work for the smallest consumption of power. In order to render the comparisons more complete, one hole had been bored by hand in the old-fashioned way, two men striking and one holding and turning the chisel, and the results were added in Table 1. Two hand-power drills had also been tried, which did not work at so great a speed as the three men with the old-fashioned hand drilling. The latter did much better work; still he thought even the makers of the hand-power drills would be glad that the trials had been made. Although his own name was attached to this paper as one of the judges, and he had suggested that it would be interesting to lay the facts before the Institution with a view to getting a discussion upon the subject and eliciting further information, the work had been done by Mr. Davey, and the preparation of the paper was due to the trouble taken by him.

Dr. C. LE NEVE FOSTER, H. M. Inspector of metalliferous mines, said that, with respect to the recent trials at Sydenham being the first trials of rock drills in this country, he recollected that as long ago as 1867 there had been a trial of rock drills in Cornwall at the exhibition of the Royal Cornwall Polytechnic Society; and since that time there had been various other trials of rock drills in that county, including a competition very similar to the present at the jubilee meeting of the Polytechnic Society in September 1882. He had been present at some trials that were held on the surface at South Roskear mine in 1877, and at others a year or two afterwards at Wheal Agar, during exhibitions of the Mining Institute

of Cornwall. The trials were not only of rock drills driven by compressed air, but comparative tests were also made with a hand-power rock drill and with hand drilling, a hole being bored by three men in the ordinary way. As to the value of the trials themselves, he was scarcely inclined to think that a mere trial of a drill for a few minutes in the open air above ground afforded any useful indications with regard to its value as a machine which was to be used day after day underground, handled by men accustomed to treating machines only in a rough manner, and under conditions where there was a great deal of dirt and dust, and often a great deal of wet—conditions totally different from those which obtained on the surface. So short a trial of a rock drill might be compared to a man running a quarter of a mile race on a spurt, as a test for judging whether he was capable of making a long march; he might be capable enough of winning the short race, but might be altogether unable to walk from London to Brighton in his ordinary clothes and to do it day after day. Therefore without wishing in any way to prejudice the winners of the race in the competition of rock drills, he thought too much stress should not be laid upon the fact of winning in such a competition. On the other hand he was delighted that the recent competition had taken place, because it had had the effect of leading to the reading of the present useful and instructive paper, and to the illustration of the construction of several of the drills by means of the diagrams now exhibited in connection with the paper.

The President was sure the Members would be glad to hear some observations on this subject from Mr. J. H. Collins, who had formerly been the Secretary of the Royal Cornwall Polytechnic Society, and had kindly acted as joint Honorary Secretary for the delightful Summer Meeting of this Institution held in Cornwall in 1873.

Mr. J. H. Collins could corroborate what Dr. Le Neve Foster had stated about the trials of rock drills in Cornwall, many of which had been on an extensive scale; and he believed the result of those

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trials had been to cause rock drills to be used much earlier in Cornwall than they otherwise would have been. With regard to future trials, there were one or two things which he thought might well be looked forwards to. In the first place, although there was not the means of getting any trial in an exhibition to compare with the trial in a mine, there were still some advantages in getting up trials in connection with exhibitions, and those advantages were chiefly concerned with the getting together of a larger number and variety of machines. But undoubtedly the best trial of all would be to choose some level underground in a mine, where the rock was pretty even in texture and was much harder and more difficult to bore than granite; and then to get all the different makers to send their drills there to drive say ten or fifteen fathoms in that level. That would be a test which would be of great value, and he should think it was not quite impossible to arrange such a trial, although it would undoubtedly be difficult to do so. Two or three things would then come out, which had not at present been ascertained: particularly the difference of boring holes in different positions. Some drills would bore a hole downward quite easily, and their disadvantages did not appear so long as they had to bore downward; but in general in a mine nearly all boring was either forward or upward, comparatively little sloping, and none at all downward except rarely in a shaft. It was plain that a heavy drill would have a much greater advantage in boring downward than a light one, and a much greater disadvantage in boring upward: so that, if the relative merits of the present drills were to be decided from the results of the recent contest at Sydenham, the heavy drills would perhaps have an advantage which they ought not to possess. Then again in certain drills some of the moving parts might wear out quickly, but they might be parts which could be easily replaced; and this would of course be a great advantage, perhaps more than making up for a more durable drill in which the parts were more difficult to replace. Moreover it must not always be considered that the amount of power used was vital. In some places miners were fortunate enough to be able to get their compressed-air power so cheaply, from water power or some other natural facility, that they would look rather for a handy drill, which

could be moved about easily and repaired easily and did not get out of order quickly, especially since the time actually employed in boring was always small as compared with that spent in adjusting the machine for each new set of holes, so that general handiness must necessarily be of great importance ; and they would not much consider whether a drill used a large or a small proportion of air. A little consideration would show a great many more conditions which should be laid down by and by in trying to arrange for more complete comparative tests of rock drills.

Mr. George Addy noticed from Table 1 that the Ingersoll-Mayne drill was the only one which used a cutting tool or drill having the cutting edge in the form of a cross +, whilst all the other drills used the straight cutting edge — of an ordinary chipping chisel. It appeared to him that the seeming failure of the Ingersoll-Mayne drill was caused, not by any defect in the machine itself, but by the cross form + of the cutting edge. Whilst this form of cutting edge was suitable for working on soft stone, he believed it was altogether unsuitable for working on granite, or on hard granite at any rate. It was pretty well known that granite, after it came from the quarry and had been exposed some time to the action of the air, was considerably harder than when first quarried ; the granite sets used for paving streets, he was told by those who occasionally had to work them, were considerably harder after they had been down for a number of years. When working on soft stone there was no doubt that the cross-shaped cutter got through the work considerably more quickly than the chisel-edged drill. It was a pity that the drills which had been broken in the trials were not exhibited to the meeting, as probably the fracture would have shown whether the quality of the steel was at fault or the temper. Considerable trouble he knew was experienced at times in getting drills which would stand satisfactorily.

Mr. Henry J. Coles noticed that in the first page of the paper the drills exhibited were divided into three classes, the third consisting of valveless drills ; but of this class no specimen had been exhibited.

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Amongst the makers of drills he thought the principal point for discussion was the particular kind of valve used. Some eighteen years ago he had been connected with the construction of what he believed was the first valve ever made in this country of the kind worked by air pressure: though in that instance it was worked by steam. It had not been successful for certain reasons, the first of which he believed was that the length of the valve itself was too great, and the valve-box was somewhat irregular in shape: so that, when the steam was admitted into the valve-box, the latter changed its shape slightly with the heat, and therefore the valve, in order to work at all, had to be made rather a slack fit. Moreover the valve was worked on the steam-engine principle of admitting the steam pressure to work it, and it was supposed that the exhaust at the opposite end would keep good during the whole time of the stroke; but it was found that the leakage past the slack valve destroyed the exhaust, and therefore when the steam was admitted at one end of the valve it did not act, because there was no exhaust at the opposite end. In drills of modern design the action of the air-worked valves depended upon the opposite principle, namely that the leakage past the valve supplied pressure to both ends, so as to keep the valve in equilibrium until the air was exhausted from either end, when the pressure on the other end immediately reversed the valve; and this had been the cause of the success of the air-worked valves in the present drills. With tappet drills also he had had considerable experience, having set to work the first Ingersoll drill that came to this country: not the modern form shown in the drawings, but the original drill, which had done efficient work. Having been connected with several other tappet-valve drills, as well as with drills in which the valve was worked by air pressure, the conclusion he had arrived at was that the air-worked valve was the superior plan. In tappet-worked drills there must be a hard piece of steel projecting into the cylinder, to be struck twice by the piston for every blow of the drill. It was scarcely necessary to say how liable a pretty hard piece of steel was to flaws, and how liable it also was when struck to chip and fly; little chips then got into the cylinder, and prevented the drill from working. That could not occur with the air-worked valves.

Moreover the kind of valve generally used for tappet-worked valves he thought was not likely to keep its shape so long as the cylindrical form mostly used for air-worked valves. In the "Rio Tinto" drill, Plates 33 and 34, he noticed that the cylindrical form had been adopted for the tappet-worked valve, thus confirming his view that any other than cylindrical valves were not likely to keep their shape for any considerable length of time, owing to the shocks and the way in which they worked, which was not to be compared with the working of the valves in a steam engine. It might possibly sometimes happen that a little dirt in the valve-box would stop the air-worked valve, which would not happen in the case of a tappet-worked valve, where the force of the piston acting through the tappet would drive the dirt away or grind it in. But even in that case it was preferable to remove the dirt by proper means, when the air-worked valve was stopped by it, rather than to let it be jammed along in the valve-box by the full force of the piston. In the description of the Daw drill it was remarked (page 147) that with an air-worked valve trouble was often caused when fixing the drill, by the valve dropping into its central position, thereby cutting off all air-supply to the cylinder. Such an objection he thought must apply to that particular design of drill alone; for he had never found it occur in any other drill with an air-worked valve.

With regard to the feeding, there were no power drills exhibited or tried with an automatic feed. Some time ago, self-feeding drills had been much thought of; but he believed it had been found that the best feeding was that done by hand by an experienced man, who there was no doubt could by means of the feed handle keep pace correctly with the action of the drill against the stone; and in this consisted the true art of working a rock drill. In page 154 there was a remark that the principle of the steam-hammer, which struck a dead blow, did not appear to have been adopted in rock-drilling machines; but an experienced driller he believed would just find the condition under which the drill struck its hardest blow, and would then keep the drill up to that condition, which he could feel well by its working; and he would not have recourse to the cushioning mentioned in the paper, which would evidently impair the action of

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the drill in regard both to the force and to the rapidity of its blows. Any one who had watched the drills worked in the trial at the Crystal Palace would have seen what a difference was made by the experience of the man working the drill. The competition to a large extent lay between the men themselves, because so much depended upon their skill, and one man could work a drill so much better than another could. Another objection to the use of an automatic feed on rock-drilling machines was that it was necessary to have a tappet of some kind either inside or outside the cylinder, which must be struck by the piston or the piston-rod every time it was required to feed the drill forward. That involved the same disadvantage as having any other tappet in or on the cylinder; it was likely to split and break, and cause more or less damage to the machine.

With regard to the remark made in page 154 respecting his own drill—that its full capabilities were unfortunately not properly tested, because the air was throttled at the inlet cock—that was the result of over-confidence in letting the drill be tried without having taken the precaution to overhaul it before it was tested. On the day of the trial, when it certainly worked very poorly indeed, he had not been able to be present himself, or to send any one to work the drill but an ordinary fitter from the shop, having no miner to work it. On examining next day the stopcock which admitted the air, he found that the hole through it was only about a quarter of an inch diameter, admitting scarcely any air to the drill. This was immediately set right, with a view to entering the drill for the tripod competition on the following day; which however could not be allowed, on account of the application not having been made early enough beforehand. Still wishing to have a fair trial, he bought the same piece of stone from the exhibition and placed it in his own works, and asked Mr. Davey to conduct a trial of the machine, and give him a report of its working under exactly the same conditions as those at the Crystal Palace, with the only difference that there was now a full-way cock on it, instead of one that was throttled. In this trial at his works also the drill was simply worked by the works manager, not by a miner, with the result that it did as good work as it ought ordinarily to do, although it might perhaps do more if it had a more experienced driller to work it.

With regard to the form of the cutting edge of the drill, he considered the chisel-shaped edge was the best, where there were no flaws or fractures in the stone; but in a different kind of stone, of varying texture and containing flaws, the chisel-point jammed.

With respect to the steel itself, he had always found that the higher the price paid for the steel, the better was the work done with it. Recently he had heard of drills being made of steel costing only 18*s*. per cwt., which he was satisfied could not pay; and he understood it had been found necessary to send out two or three times as much of this cheaper steel as would have been required if the best steel had been employed. The length of time that a drill could be kept sharp depended generally upon the price paid for the steel.

One of the rules laid down for the recent competition was that the hole bored should be half the diameter of the drill cylinder. But such a stipulation he thought did not put all the drilling machines exactly on an equality, because the weight of the moving parts was more nearly in proportion to the cube of their diameter, while the areas of the hole and of the cylinder were in proportion to the square of their respective diameters. In the larger drills therefore the moving part would have so much greater force in striking a blow, while the recoil would return it about as quickly as in the smaller drill. In other respects he thought the rules were satisfactory, and that the whole trial had been conducted throughout in the fairest possible manner, and to the satisfaction of every one concerned.

Mr. William Schönheyder mentioned that about twenty years ago he had been experimentally endeavouring to improve a drill having a valve worked by air pressure; it was not a long valve like that mentioned by Mr. Coles (page 166), but a short one, so that there was no difficulty about jamming in consequence of expansion. The drill was tried both with steam and with air. The difficulty of which Mr. Coles had also spoken (page 168), arising from the use of a tappet for advancing the drill automatically, did not exist in that machine, inasmuch as the automatic advance was made by means of a separate feed-cylinder, which was worked from the main

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cylinder: the moment the main piston made a longer stroke, after the hole had been drilled to a certain depth, it opened a port admitting air into the feed cylinder, by which the drill was then advanced on its stand through the required distance; in that way an automatic advance was obtained without any striking of tappets.

It was interesting to see the simple manner in which in some of the drills exhibited the bit or chisel was fastened into the piston-rod by forcing a taper shank into a taper hole. It was the same plan that was generally used for stamps, and he believed it answered well. At the time of making his former experiments he remembered there had been a great amount of trouble in holding the drill in. It was generally put in with a parallel shank up to a square shoulder, and a key was driven in through a transverse slot in the shank and the socket. But when boring in a hard material, the drill always worked loose. That difficulty seemed now to have been overcome by the taper shank fitting tight in a taper socket. In the Ingersoll-Mayne drill however, Figs. 19 and 20, Plate 38, the old-fashioned mode of holding the drill seemed still to be adhered to, with the slight modification described in the paper (page 146); and he should be glad to know whether it was found efficient.

As to how far the value of a drill should be judged by the amount of air it consumed, no doubt the consumption of air was a matter of some importance, just as in a steam engine it was of importance to know the amount of steam used; nevertheless there were many other considerations which also determined the value of a drill or of an engine. If the air used in the drills was to be measured at all, he would suggest that in any future trials some other apparatus should be employed than the meter described in the paper. The latter was of the ordinary inferential kind used for measuring water; and it was well known that, although it did good service in measuring water where the flow was sufficiently quick, yet when the flow was sluggish it became irregular in registration, and ultimately stopped altogether for a still smaller flow. With the 2-inch meter used in the recent trials it was seen from Tables 2 and 3 that the quantity of air ranged from 15 to 30 cubic feet per minute. Substituting gallons as the

usual measure for water, 20 cubic feet per minute were equivalent to 125 gallons per minute, on 7,500 gallons per hour. If these were gallons of water instead of compressed air, a 2-inch meter would no doubt register fairly accurately; but as the inferential meter was worked entirely by the current of air or water impinging against the vanes of the revolving fan, it must be ascertained with what force the air struck them as compared with the water. Taking the relative weight of air at atmospheric pressure and of water as 1 to 820, and making allowance for the air being compressed say to 60 lbs. per square inch above the atmosphere or 75 lbs. absolute, that is roughly a compression of five times, the relative weight of the compressed air and of water would be as 1 to 164; and he thought therefore it was fair to say that the air would strike the vanes with only about 1–164th of the force of water. In other words, the meter was worked under conditions similar to those which would obtain if only $7{,}500 \div 164 = 46$ gallons of water per hour were passing through. With so small a flow of water an inferential meter of that size would scarcely go round at all; and when used as an air meter the fan would in certain positions let a corresponding flow of air pass through it without any measurement at all. If therefore a meter of this description were to be used, it would be desirable in future trials to employ a much smaller size, which would be amply large for air; and a much more accurate registration would thereby be obtained than was possible with the larger meter used in the recent trials. If it were possible, by far the best way of measuring the air would be to discharge the exhaust air into some kind of gasometer, which for the small quantity of air used in a short time would not be a large or expensive appliance, and would give accurate measurement.

Mr. Carbutt mentioned that neither Mr. Davey nor himself was responsible for the air meter that had been used. They had been called in at short notice simply to act as judges, without being asked to give any opinion whatever as to the conditions of the trial or as to the apparatus. The meter had been kindly lent for the occasion by the makers, Messrs. Tylor and Sons, whose partner Mr. Bright was present, and would perhaps be able to say something more about it.

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In one case it would be observed that the amount of air used had been left out in the Tables, because they had been convinced that the meter was not registering the amount of air going through, owing in their opinion to the slow speed at which it was flowing. There had not been either the opportunity or the time to provide a gasometer for obtaining a positive measurement of the air used; the exhibition had closed within a day or two of the trials, and it had been a drive to get them done in time.

Mr. PHILIP BRIGHT explained that he had been asked only two days before the trials were made to lend a meter for registering the air used by the rock drills. At that time he happened to have only one air meter available, which had an inlet and outlet of 3 inches diameter. The size of the air pipe he was informed was 2 inches diameter; but he could not get any information as to the amount of air which was likely to be used by the rock drills. Being most anxious not to hinder the free passage of the air, so that there might be no hitch through an insufficient supply to any of the larger drills, he offered to lend the 3-inch meter, knowing that it would at least be amply large for the use to which it was to be put. This meter was therefore put on the supply pipe; and in some cases it appeared to have registered the full quantity of air, but with one of the drills it hardly moved. The test made before the meter was sent out was imperfect; it was tried only with water at full speed, and it could not be tried then at a slow speed also, with small quantities of water running through, because there was not time for this to be done. When it was received back again after the drill trials, he found on testing it that it had been binding on the toe-piece considerably, and was not so sensitive as it ought to be; but after the toe-piece had been eased, there was no trouble at all in running at lower speeds, and with water it registered with absolute correctness as small a flow as only 100 gallons or 16 cubic feet per hour. Having no appliances at hand for testing with air, he had been unable so to test this meter; but from the tests he had made with other air meters at Birmingham he had found that the water tests showed exactly the same results as air, when the meter was

running at full speed. The present meter differed materially from that described to the Institution in 1882; it had since been altered and improved in many ways, although the mode in which the water or air impinged upon the vanes of the fan was practically the same.

Mr. ARTHUR L. COLLINS had had practical experience of the working of a rock drill in comparison with hand-boring. The mine in which the trial had been carried out was in Norway; and the rock was extremely hard gneiss, far harder than the hardest granite. The machine was not one of those described in the present paper, but a $3\frac{1}{2}$-inch "Cornish" drill, which, though made by a different maker, was similar in principle to McCulloch's "Rio Tinto," the valve being worked by a tappet from the piston itself. The steel used for the bits was certainly expensive enough, costing sevenpence a pound, so that it presumably left nothing to be desired in the way of quality. The cutting edge of the bits was generally sharpened in chisel form. A good many were sharpened in the cross form, and were used for starting the holes, because where the holes had to be started on an irregular or inclined surface it was essential before the chisel-bit was used that the surface should be about at right angles to the line of the hole. The cross drill was also used in a few cases, where after boring for some time the chisel-shaped drill "fitchered" as it was called, that is, caught in a joint or in a soft place in the rock.

The first thing noticed was the large proportion of time lost in various ways, and the small proportion of working time when the drill was actually boring. For example, in very hard rock it was found that the borer would last for boring only 4 inches depth at a time, and then it had to be changed. Changing the borer occupied an appreciable amount of time, especially when it was considered that each time the drill was changed a drill of slightly smaller size had to be put in, so that it might enter the hole and work freely without catching. A slightly longer drill had also to be used, because as the hole advanced a longer borer was required for enabling the machine to bore at all. A great deal of time was also lost in setting up the machine, because the bar that was used for holding it was so heavy

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and so difficult to adjust. Then again it was found that one shift out of four was entirely lost in the blasting of the holes bored. So that altogether, at a rough estimate, the machine was boring for only one-fifth of the total time, the rest of the time being taken up by other necessary work, apart from actual boring. The best machine for practical work was soon found to be that which was handiest, and which would allow the work that at present occupied much the larger part of the time to be done quicker.

The tests with which he had been concerned had been made underground in the same level, which was first driven six months by hand labour; and then with the same men, through the same rock, and under exactly similar conditions, it was driven for seven months by machine. The air was supplied at 60 or 70 lbs. pressure, which was about the ordinary pressure that drills were worked at. The great gain with the boring machine was found to be the increase in the speed; whereas by hand-boring a length of only 3 fathoms per month was driven in that extremely hard rock, the machine enabled half as much again to be driven, or $4\frac{1}{2}$ fathoms per month. The cost per fathom was found to be about the same. The driving was set to different numbers of men at different times; but the average cost came out the same, exclusive of compressing the air, which was done by water power costing little or nothing. It was a curious fact that, the price per fathom being the same, with hand labour 30 per cent. only of the total price went for dynamite and other materials, and 70 per cent. went directly to the men as actual wages; but with the machine half as much again or 45 per cent. was necessary for dynamite, while only 55 per cent. went to the men as wages. It seemed therefore that a great deal more dynamite was necessary per cubic fathom of rock broken, and a great deal less labour. The dynamite had been carefully weighed out every month to the men, who had to pay for it themselves in the ordinary way; and it came to $1\frac{1}{4}$ kilograms of dynamite per cubic metre of rock broken with hand labour, or 20 lbs. per fathom of level driven, the size of the level in the clear being 2 metres or $6\frac{1}{2}$ feet square; whereas with machine drilling it was 2 kilos or 32 lbs. of dynamite. So also in regard to the consumption of steel. The borers were weighed out at the commencement of the month and

weighed in again at the end, and the difference represented the loss of steel, which with hand labour amounted to about 0·3 kilogram per cubic metre of rock broken, or about $4\frac{3}{4}$ lbs. per fathom forward. With machine drilling a better quality of steel was used, with the result however that as much as half a kilogram of steel was worn away per cubic metre of rock, or $7\frac{3}{4}$ lbs. per fathom forward, showing a great difference from hand labour. The hand-boring was done single-handed by the ordinary Norwegian method: instead of two men beating and a third holding the borer, the same man held and beat; with one hand he held the borer and turned it, and with the other beat with a light hammer, having a head weighing only about 4 lbs. Small holes only were bored, the borers most commonly used being made out of $\frac{7}{8}$ or $\frac{3}{4}$ inch steel. In boring with the machine it was found that the average depth of hole for which each borer could be used was only about $4\frac{1}{3}$ inches, nine borers being blunted per metre; consequently in making a hole to the average depth of 4 feet, the borer had to be changed about eleven times. That was where so large a proportion of the time was lost, that the speed of the actual boring was of comparatively little importance. In very hard granite the machine was found to bore at the rate of close upon six inches in a minute; but in the gneiss rock it bored only a little over one inch. In the latter case therefore the progress was much slower, in addition to the time actually lost in changing the drills, which had to be changed so much oftener. In the cost per fathom, which he had found to be the same for machine work as for hand-boring, there was not included the extra expense of sharpening the borers of the machine, which cost a great deal more to sharpen than the hand-borers, partly because the steel used for the machine drills was heavier, and partly because it was of better quality and therefore wanted more skilful men to temper it. This extra cost however, pertaining to the machine drills, would not materially alter the result already stated.

A suggestion which he wished to offer was that some method should be adopted, though he did not quite see how it was to be done, for altering and adjusting the amount of turn given to the borer, to suit the different kinds of rock. A skilful miner boring by hand varied considerably the turn which he gave to the borer. In granite

(Mr. Arthur L. Collins.)

it might be that he would turn it each time through as much as one-sixth of a revolution, but in hard gneiss he would not turn it more than one-twelfth or one-fourteenth; while in soft shale rock he would turn it even more than one-third round. The boring machines as at present constructed were set to one definite turn of about one-quarter of a revolution, and there were no means of altering it. In hard and tough hornblendic gneiss or in hard tin capel, if the turn were small enough, the borer would chip off a little piece of rock from where the last blow had struck; but the present turn was so great that when working in such an extremely hard rock it was found there was no chipping at all; the borer was simply driven end on against the rock, and merely pounded it into dust instead of chipping off much coarser stuff. In granite, for which the turn given to the borer by the machine was about right, the stuff that came out of the hole was many times as coarse as that which came out of harder rock like gneiss; and this he believed was largely due to the fact that the same turn was not suitable for the two different classes of rock. Any simple means therefore of adjusting the turn to the quality of the rock would be of great value he considered to practical mining.

The following was a tabulated summary of the general results obtained in the comparative trial, the costs here given including no allowance for interest on capital or for depreciation:—

	Hand Boring, Five months.	Machine Boring, Seven months.
Average distance driven per month . .	3¾ fathoms.	4⅝ fathoms.
Average cost per fathom forward . .	£5 6 0	£5 5 0
Cost of dynamite and other materials . .	£1 11 10	£2 7 3
Cost of labour	£3 14 2	£2 17 9
Average wages earned per man per day .	2*s.* 8*d.*	3*s.* 3*d.*
Dynamite used per fathom forward . .	20·17 lbs.	32·14 lbs.
Steel used per fathom forward . . .	4·75 lbs.	7·75 lbs.
Holes bored per fathom forward . . .	—	32·17
Average depth of holes	—	43·50 inches.
,, ,, bored without sharpening .	—	4·33 inches.
,, ,, bored per shift . . .	—	13 ft. 10½ ins.

The size of the level in the clear, as previously mentioned, was

2 metres or 6½ feet square. For working the one machine used, four men were employed, Swedes and Norwegians, in two shifts of two men each, working about ten hours per shift; although skilful miners they had had no previous experience in machine drilling. The explosives used were dynamite No. 1 and gelatine dynamite, which were paid for by the men at cost price; no charge was made for compressed air or for sharpening the borers. All time lost in blasting, changing borers, and fixing and removing the machine, was included in the foregoing statement. As the level advanced, there was perhaps a slight increase of hardness in the rock, rendering the conditions if anything rather less favourable for the machine which drove the later portion than for the hand labour by which the earlier portion was driven.

Mr. REGINALD BOLTON had had some experience during fifteen years with a number of rock drills, having set to work the first Eclipse drill that had been tried in England, which he believed was the first successful drill that had been brought to this country having the valve worked by the air pressure, as shown in Figs. 27 and 28, Plate 40. That plan of valve seemed to him to have been copied in some respects in several other drills. The Eclipse drill was used both in the United States and in this country; and the result attained with it in the recent competition he thought did not represent either what this machine could do, or what other machines could do, under more favourable circumstances. With a 2½-inch Eclipse drill and with a higher pressure of air he had himself seen a 1½-inch hole drilled in Leicestershire granite to as much as 12 inches depth in one minute. No doubt that was an excessive result which would not be attained in practice; but it showed what might be done with an effective pressure of air, a steady tripod, a nice piece of rock, a good sharp borer, and also good management of the feed by hand.

The rotation of the borer he considered was one of the crucial points with all rock drills, and one which had given more trouble in the past than anything else. Even when the valve tappet had been got rid of, the rotation still presented the objection that, with two

(Mr. Reginald Bolton.)

or three pauls working upon a ratchet-wheel in the cylinder cover, there was a liability to little pieces of steel getting chipped off and finding their way into the cylinder; because whenever the drill was not making its full stroke the point of a paul and the point of a ratchet-tooth might be brought together in such a way as to let the ratchet-wheel slip back a little, and the paul was then apt to get a bit chipped off, which might even tear the whole of the teeth away. Even with ratchet-wheels made of the best steel that could be bought, costing over 70s. a cwt., he had known every tooth stripped off the ratchet-wheel with the hard work upon such material as the tin capel in Cornwall. To the crown-ratchet clutch in the Climax drill, Fig. 6, Plate 35, there seemed to him to be still the same objection: there were fifteen teeth to each half of the clutch, and therefore fifteen points that rose and slid upon one another and had to pass over and engage one another; fifteen points therefore at which there might be a piece of steel chipped away, and that was a disadvantage. Moreover the true idea of a ratchet-wheel and a pair of pauls was, as shown in Fig. 2, Plate 33, that there should be one paul fully engaging a tooth, while the other paul was half way from a tooth, so that at any rate there was always the chance of catching the tooth half way. In the Cranston drill, which had been in use a great many years, particularly in the north-east of England, the rotation was effected by hand, by means of a handle standing out at the back of the drill; and the same feature had characterised the Daw drill invented thirty-five years ago; but in all the modern drills the arrangement of ratchet and pauls with rifled bar appeared to have become stereotyped.

With regard to the valves, it would be observed that there was a similarity between the Eclipse, the Coles, and the Bickle drill in the cylindrical shape of the valve-box, which was compact and not easily damaged: except indeed in the Coles drill, in which it seemed to him that the gun-metal valve-box was far too slight to stand such rough treatment as he had seen dealt out to a drill; namely, when it did not altogether do what the miner liked, he struck it with the first hammer or stone that he came across, and vented his spite upon it. The use of gun-metal for the valve-box of a drill he thought had

always proved more or less a failure. The Eclipse drill exhibited upon a tripod was one in which he had first put a gun-metal valve-box, and it had given considerable trouble. The external cross ribs in the drill exhibited had had to be put on in order to stiffen the valve-box, because it was so slight that even the air pressure of 90 lbs. per square inch deflected the valve-box somewhat, and the valve was not free to work.

In the Ingersoll-Mayne machine the cross-shaped or four-way drill used in the competition had been made of good steel, and seemed to him in that respect to have been about equal to any of the borers now exhibited; but it had undoubtedly been over-hardened, in the effort probably to get as hard a drill as possible, and the little excess of hardness had spoilt its performance altogether. The machine itself he considered was a good one, and it worked in a successful manner.

In all percussive rock drills it seemed to him that more attention ought to be paid than at present to the force of the blow. All kinds of ingenious arrangements were elaborated in regard to the valves, the cradles, the tripods, and other parts; but the force of the blow seemed to be left to take care of itself. The work done upon the rock however seemed to him to be the first thing to be considered. The tool striking against the rock was a rather blunt knife-edge; and if it did not strike a sufficiently powerful blow, no effect was produced. Even with a tolerably sharp cutting edge the force of the blow might be so much reduced by wire-drawing the air that the tool might pound away upon a piece of granite without making the slightest impression. But if the pressure was increased to the ordinary 60 or 70 lbs. per square inch, the drill was then able to penetrate the granite; and if it were still further increased up to 90 or 100 lbs. per square inch, the drill would work far more effectively. That was the direction in which he considered drilling could be improved; and the improvement lay chiefly with the manufacture of air-compressors. Most of the present drills would be safe with a pressure of 90 or 100 lbs.; and even up to 120 lbs. he thought that far better results would be got economically out of all the drills now in use. This anticipation appeared indeed

(Mr. Reginald Bolton.)

to be borne out already in modern practice; for he had been told that last summer it had become more generally the practice to increase the pressure of air used in rock drills, and that they were doing better work in consequence. Some recent rapid boring in the United States had altogether eclipsed anything done in this country in the way of advancing tunnels; and it had been accomplished simply by using a higher pressure of air, which he expected would be adopted in this country after a short time.

The record given in the paper of the results obtained in the competitive trial appeared to him to be of no practical value, inasmuch as the trial itself, so far as he could see, had established nothing, and could establish nothing; it formed no test of what the several drills would do in practical work. The conditions, in regard to which the judges had had no voice, in his opinion were not fair to the drills; for the stipulation that each machine should bore a hole of half the diameter of its cylinder seemed to him not to establish a proper ratio between them. Moreover in respect of working pressure many drills were constructed to work habitually at low pressure, in some cases not more than 50 lbs. per square inch. Others on the contrary needed a higher pressure to get any results; and if there had been an opportunity of increasing the pressure in the trial this would have been found out. It was naturally a difficult thing to establish a comparison between rock drills, owing to the character of the work they had to do; nevertheless it was seen from the remarks of previous speakers that various attempts had already been made to establish the work done by different drills under similar conditions of practical working. Too often the results even then had not been wholly reliable, owing to the competing drills not meeting with altogether impartial treatment at the hands of the men working them, by whom their relative values were sometimes inverted under the influence of other considerations than those of actual merit. In connection with the Royal Agricultural Society's trials of steam engines, he had seen engines got up for the purposes of the trial, and ostensibly as far as outside appearance went they were ordinary farming engines; but the piston was not the same as it would be in the ordinary engines, and with regard

to the valves there were sundry little modifications that had a remarkable effect in the trial. So far had this been the case that on the occasion of one of the last of these trials it would be remembered the bulk of the manufacturers of portable engines had declined to enter into the trials any longer. The rock-drill trials which had now extended over a considerable number of years had not established in his opinion anything more than the ability of the men working the drills. For the measurement of the air consumed by the drills, the use of a water meter he considered was no more appropriate than would be the use of a gas meter for measuring the steam supplied for working an engine. By charging a large reservoir with compressed air up to a certain pressure, as he had done himself, and then starting the drill and keeping it going until the air had run down to a certain lower pressure, an absolute measurement was obtained of the actual amount of air used by the machine for performing a measured amount of boring in the rock upon which it was working when so tested.

As regarded hand-power machines, he had had some at work, but had never found men who could stand working them for more than half an hour at a time, as the labour was so exhausting. A longer trial than the twenty minutes allowed in Table 1 for the hand machines would have been out of the question.

Mr. WILLIAM S. LOCKHART had seen a great deal of hand drilling done single-handed by one man working the drill and the hammer, as described by Mr. Collins (page 175); and although the trials recorded in the present paper were of power drills, it would have been interesting, since three such good men had produced such a really astonishing result by hand-boring as 22 inches depth of hole in $18\frac{1}{2}$ minutes, to see whether those same three men working singly could also have bored altogether an equal capacity of hole. In Europe he had found that men working by piece-work could almost invariably make more money single-handed than when working together in twos or threes, one or two of them striking and one holding and turning the drill. In Upper Burmah he had recently had occasion to do a great deal of blasting with poor native

(Mr. William S. Lockhart.)

labour, having in fact had practically to train his own drillers. The single-handed plan he had found the most useful; but instead of the 4-lb. hammer mentioned by Mr. Collins (page 175) he had used only a 1½-lb. chipping hammer and ¾-inch octagonal steel for the drill, which was about 15 inches in length for short holes. For deeper holes the length of the drill had to be increased, and then sometimes another man had to be put on to strike; but for short holes he found the single-handed method answered best. For the kind of rock that was being blasted it answered particularly well, and especially for blasting in adits, because so many more holes could be got in the working face. Working in the manner usual elsewhere, with two men striking and a third holding the drill, not more than two holes at a time could be bored in the face, because there was not room for more than six men to work together in the end; but with the same six men each working singly, six holes could be got in at a time; and as shallow holes there answered the purpose, a good deal more rock could be got out in the same time. He did not know whether that method was used much in this country. It was novel he believed in Burmah until he introduced the method there, as its adoption for the work that he had in hand seemed altogether new to those who had been doing blasting in the same district for road making, for which the universal plan had been to drill 1½-inch holes with two men striking and one holding the drill. The single-handed method however he had found much quicker and much handier altogether, as more holes were got in at a time. He enquired why the hand-boring trial recorded in Table 1 had lasted only 18½ minutes, instead of the whole time allowed of 20 minutes. Were the men exhausted before their time was up?

Mr. HENRY DAVEY replied that they stopped because the hole had gone through the stone, which was only 22 inches thick.

Mr. THOMAS WILSON considered that the McCulloch drill ought not to be classed as entirely a tappet-valve drill, inasmuch as the working of the valve depended both on the tappet and on the air pressure. The piston striking the tappet knocked the valve over into

its proper position for admitting the air to the cylinder, and at the same time the air acting on the end of the valve held it in its proper position, preventing any movement of the valve while the boss on the piston was out of contact with the tappet. In some other tappet-valve drills a spring was used for the same purpose; but it often happened that the spring exerted a great deal more pressure than was actually necessary to hold the valve in its place, and the consequence was that a needless amount of friction was produced on the face of the valve, which caused extra wear not only on the valve itself but also on the tappet and on the boss upon the piston. The valve of the Ingersoll-Mayne and some other drills had no spring, being held in its place by the air or steam itself. The area of the valve in the Ingersoll-Mayne drill was so large that the total pressure of the air upon it was very heavy, and the wear on the face was consequently excessive. In the McCulloch drill the air acting upon the end of the valve exerted no pressure on the face; therefore the wear and tear which was so general in other tappet-valves was here saved, and the piston had no great resistance to overcome in striking the tappet and throwing the valve over. In drills having the valve worked entirely by air pressure the motion was fairly reliable while the valve was comparatively new, provided no sand or grit got in between the working surfaces. Moreover the rust forming in the interior of the main air-pipe would get into the valve, and the increased friction so caused was more than the air pressure could overcome; consequently the valve had to be taken out, and the rust or grit cleared away, which involved a large loss of time. With the tappet valve the blow of the piston was sufficient to drive such an obstruction away, the tappet giving the valve a positive motion; whereas the valve worked by air had not a positive motion, and consequently, even supposing that no grit got into it, yet when it became worn to a certain extent the air passed by it, and caused it to flutter, that is, not to go clean over as it should do.

The President said that letters had been received from gentlemen unable to be present, which it would be well to read before the discussion closed.

Mr. JAMES STEVENS, representing the Bromfield-Ingersoll hand-power drill, wrote that the paper itself was interesting to all concerned in mining; but the trials made with the hand-power drills and with hand-drilling, recorded in Table 1, were in his opinion entirely useless as practical tests. Men working by hand labour with drills and hammers could not possibly have kept up the rate of work which was done in these trials; whereas the Bromfield-Ingersoll hand-power drill could have kept on all day at a comparatively high rate; and a series of valuable tests in America, extending over many weeks of regular work, had proved that it would beat any two sets of hand-drillers. Had the recent tests been continued during say four hours, which in his opinion was the least time that should have been given to them, the results he considered would have been altogether different. In hand-drilling the question was not how many inches could be drilled in twenty minutes, but how many inches could be drilled in a day; that was how the question really presented itself to a mine manager, and this point seemed to have been entirely overlooked in the recent trials.

Mr. DAVID JOY wrote that in 1867 he had arranged with Messrs. Bell Brothers, of the Clarence Iron Works, Middlesbrough, to construct for use in their Upleatham ironstone mines a rock drill on the principle of a steam hammer, which latter he was then making as a speciality. The peculiar valve used in the hammers rendered it possible to produce a rock drill so simple as not to be damaged by the rough usage it would have to undergo in the mines; there was no machinery to move the valve, which was worked entirely by steam from the drill cylinder. That had been the first attempt he believed to drill ironstone by steam power. Steam was used to begin with because it was at hand, and compressed air would at once have increased the cost of the experiment largely; with steam it was merely necessary to cover with wood all the parts to be touched. The first machine made had a brass cylinder, $3\frac{1}{2}$ inches diameter he believed and 8 inches stroke, with brass valve-chest and valve, and a steel piston and rod all in one, carrying at its outer end one of the ordinary drills used by the ironstone miners. The whole was

supported on a movable tripod. Experiments were first tried in the manufactory on big stones of hard millstone grit, until the machine was got to work satisfactorily in drilling vertical holes. It was then taken to the mines and set to work on the ironstone; and there the greatest difficulties arose from the varying nature of the rock. The machine would work well for a time, till suddenly coming to a hard nodule, round which it would slip, thereby diverting the hole to one side and jamming itself in it. Moreover the ironstone itself was of a clogging or binding character, liable to stamp solid under the drill, so that the clearing of the stuff out of the hole was a difficult matter; the removal of the drill for clearing the hole was easily and quickly done. The turning of the drill, precisely as done by the men, was imitated automatically by the machine. Then flushing the holes with water was tried; and also the use of drills made with a helical channel round their entire length, twisting in the same direction as the automatic rotation. By these means the mechanical difficulties were overcome, till the machine could drill holes a good many degrees above the horizontal. Then occurred the crowning difficulty that the men refused to work the machine, on the plea that it would rob them of their wages; and there the matter stopped for the time. It was only left to him to congratulate those who had since fought through all the difficulties, and had not merely solved the mechanical problem, but had also rendered rock drills now a commercial success.

Mr. Richard Stephens, referring to the observation in page 153 of the paper respecting a difference in the blow produced by a drill when the valve was worked by a tappet and when it was moved by air, wrote that in his own experience he had found as dead a blow could be struck by a tappet-valve drill, if properly constructed, as by a drill having the valve worked by air; while the latter could easily be made to strike a cushioned blow by so placing the front small aperture leading from the main cylinder to the valve-chest as to reverse the valve early enough for admitting air in front of the piston before the blow was struck. Thus if the small aperture for actuating the valve were so placed that the piston should uncover it when having still to make two inches of its stroke before delivering the

(Mr. Richard Stephens.)

blow, the drill would work much quicker but would not strike a dead blow; while if it were placed an inch further forwards, the drill would work slower but would strike a heavier blow. The same applied to the tappet-valve drill, in which the blow could be regulated by the position of the forward tappet: if the valve were not reversed until the piston had got within an inch of the extreme end of its forward stroke, as good a blow was obtained as from a drill having its valve worked by air, with the advantage over the latter that the tappet valve was more reliable, whereas the best drills having air-worked valves were liable not to act from various causes, such as slackness of the piston or of the piston-valve, choking of the ports, and presence of grit.

The cylinder of the Climax drill tried in the recent competition had been broken up on its return to his works, and had been found to be a defective casting, having a blow-hole through the thickness of the metal between the front port and the interior of the cylinder. The consequence was that, the moment this hole was uncovered by the front piston in its forward stroke, the air was admitted in front of the piston before the valve itself had been reversed, and thereby the motion of the piston was retarded and the force of the blow impaired. In regard to the trial he considered there was nothing to complain of; and the fact of the Climax drill not then doing such good work as it ought to have done was due, not to any conditions of the competition, but to the unseen defect which had since been discovered.

Mr. HENRY DAVEY thought that one object of the paper had been realised in the useful discussion to which it had given rise. The short duration of the trials had naturally been rather severely commented upon; but this matter, as well as all the rest of the conditions of the trials, had been settled he understood by a conference with the competitors, who were therefore themselves responsible for the way in which the trials were conducted. It was the competitors themselves who were anxious that the trials should be made, and they had been carried out entirely with their concurrence in every respect. It had appeared to the authors of the paper that the superiority of one drill over another was more a

mechanical question than anything else; and from the remarks made in the discussion it seemed to him that this was mainly true. The drills were all more or less on one general principle, but some might be more mechanically perfect than others; and it was the mechanical construction of the drill which seemed to him more important than almost anything else.

The President said he had drawn one conclusion from the statements made in the discussion, namely that sufficient care had not been taken by some of the competitors to see that everything was in proper working order before the trials began. The knowledge gained in the present instance might be useful to others in the future. From the practical remarks made by Mr. Collins (page 174) he gathered that in machine drilling as compared with hand labour there was no saving in money, but simply a saving in time. Were it only on this account however, he had no doubt that machinery for rock boring would become, if indeed it had not already become, a most useful and valuable aid in many of the operations of mining. He had great pleasure in proposing a vote of thanks, in which he was sure the Members would cordially join, to Mr. Carbutt and Mr. Davey for having brought this interesting subject before them.

Mr. Carbutt, in acknowledging on behalf of Mr. Davey and himself the vote of thanks, said he was thoroughly satisfied with the discussion. There never had been any trials he believed with which some fault could not be found, and nevertheless the trials had generally resulted in progress. Although the trials of the Royal Agricultural Society had been disparaged by some persons, he believed they had done a considerable amount of good for agricultural engineering; they had induced both engineers and agriculturists to see if they could not consume less coal for a certain amount of work; and although every one might not be satisfied, and some might find fault, there could be no doubt that a certain amount of benefit had resulted from those trials. As to whether any similar benefit would result from the drill trials which had recently taken place, those who were practically engaged in mining were quite able to judge for

(Mr. Carbutt.)

themselves: as was evident enough from the practical remarks of Mr. Collins, which showed that he had considered every circumstance bearing upon the work he had had to do, and had looked fully at both sides of the question of machinery versus hand labour; and he desired to thank him for the figures he had placed before the meeting. Both Mr. Davey and himself were glad if the paper had been of any service to the Institution; he believed it would be of service to those who wanted to try rock drills on any future occasion.

MEMOIRS.

Peter Borrie Blair was born at Stockton-on-Tees on 31st July 1866. He served his apprenticeship under the tuition of his father, the managing director of the engineering works of Messrs. Blair and Co., in which he latterly acted as assistant manager and director. Having made electricity his special study, he fitted up successfully and completely with the electric light about twenty large ocean-going vessels; and also had under his own control the lighting of the works of his firm, which is all done by electricity. His death took place on 15th January 1891, at the age of twenty-four. He became a Member of this Institution in 1890.

Anthony Bower was born in Liverpool on 21st September 1820, and on leaving school was apprenticed with Messrs. George Forrester and Co., Vauxhall Foundry, Liverpool, where he was early placed in the drawing office, of which after Mr. Forrester's death he had charge, besides making the calculations required for estimates. The work turned out in those days was mostly machinery required for sugar making in the West Indies. Marine engines were soon added, of which were constructed what at that time were some large examples, such as those for the Holyhead steamers. In 1854 he became a partner in the firm, in the early days of the Crimean war; and the works were kept going night and day to furnish the required supply of shot, shell, and mortars. Some time afterwards he made a journey to Egypt, and obtained there large orders for steamers, sugar machinery, pumping engines &c., far beyond what his firm could cope with in their own works. In 1872 he entered the Liverpool Town Council, and devoted much of his time and energy to the question of water supply for the future, visiting all the localities far and near that were likely to be available, and notably aiding in getting the water bill passed, and in all matters that pertained to the

vast undertaking at Vyrnwy. He lived to see the completion of the great lake at Vyrnwy, of which he had done so much to realise the achievement. He was an alderman of Liverpool and a justice of the peace, and had on more than one occasion been asked to accept the position of Mayor, but had been unable to do so on account of the large amount of time that he devoted to the water committee as chairman. His health began to fail towards the end of 1889, and he was laid up for nearly the whole of the succeeding year; and he died on 31st January 1891 at his residence at Heswall, Cheshire, at the age of seventy. He became a Member of this Institution in 1870.

Archibald Douglas Bryce-Douglas was born at Ardrossan in 1839. After receiving a good education at the High School of Glasgow, and subsequently at the University, he was apprenticed by his father, Rev. John Bryce, first to a joiner at Ardrossan, and afterwards to Messrs. Randolph Elder and Co., Glasgow, at the time when they had just added shipbuilding to the construction of engines and boilers. After remaining there only two or three years, he went to New Zealand, where he had been offered a position to superintend machinery; but on the outbreak of the Maori war he proceeded to the west coast of South America, where he acted for some years as resident engineer of the Pacific Steam Navigation Company, having charge of a fleet of forty steamers, and erected their workshops at Callao. In 1869 he became superintending engineer of the company in Callao, and held that position for six or seven years. Returning to England he was appointed in 1877 engineering manager to Messrs. John Elder and Co., afterwards the Fairfield Engineering Company, and built there the engines for many well-known steamers of the Cunard, Orient, North German Lloyd, and other fleets, as well as for the British and various foreign navies. He introduced many important developments in engineering practice, and also availed himself largely of all improvements which he recognised as important. Early in 1889 he became managing director of the Naval Construction and Armaments Company at Barrow-in-Furness, and soon succeeded in giving renewed life and activity to the shipbuilding and marine engineering

industries of that town. Here were lately constructed under his direction three steamers for maintaining a high-speed service between Vancouver and Japan and China, in connection with a scheme which he was engaged in developing for a new direct route from England to Australia, across the British territory of Canada, in connection with a fleet of fast steamers intended to make the sea passage between Plymouth and Halifax, or St. John's, Newfoundland, in five days, this passage being 600 miles shorter than that between Liverpool and New York. His death took place after a week's illness at his residence, Seafield Tower, Ardrossan, on 5th April 1891, at the age of fifty-two. He became a Member of this Institution in 1888.

John Chapman was born at Charlton Kings near Cheltenham on 12th May 1826. From early life he had been engaged in works connected with gas and hot-water engineering, and carried on business for some years in Cheltenham until October 1886, when he removed to Eton, having been appointed manager and collector of the Windsor and Eton Water Works. In June 1888, the corporation of Windsor having acquired the waterworks, he was appointed their manager, and carried out considerable improvements. In 1890 he undertook some extensive alterations, to which in spite of illness he continued to devote his attention, until on 5th December 1890 he was seized with a paralytic stroke, resulting in his death on 15th February 1891 at Eton, at the age of sixty-four. He became a Member of this Institution in 1885.

William Fox was born at Low Moor, Yorkshire, on 25th October 1810, and in 1862 commenced his career as a schoolmaster at Harrow Weald in Middlesex. Shortly afterwards he established himself in Leeds, where, being an enthusiast in music, he became organist and choirmaster at St. John's Church. In 1865 he joined his brother, Mr. Samson Fox, in the engineering business of Messrs. Fox Brothers and Reffit, at the Silver Cross Works, Leeds, where labour-saving tools were made a specialty. In 1874 they converted their business into the Leeds Forge Company, and secured twenty acres of land for the purpose of its development. For about four

years he filled the position of secretary, and afterwards acted as one of the representatives of the firm. His death took place at his residence, Fairfield House, Harrogate, on 20th February 1891, at the age of fifty, from pleurisy, after two days' illness. He became a Member of this Institution in 1882.

Loftus Perkins was born in London on 8th May 1834. His father, an American citizen, who came to this country in 1827, had established himself as an engineer, and his name is principally associated with the invention of heating by hot water in a closed circuit at very high pressures, which is applied to the warming of buildings and the heating of bakers' ovens. Having entered his father's manufactory at an early age, he afterwards practised in 1853–4 as an engineer on his own account in New York. In 1854 he returned to England, and for eight years was associated with his father in experiments upon the steam gun, and in developing the steam baking oven and other inventions. From 1862 to 1866 he was in business in Hamburg and Berlin, designing and executing many plans for warming buildings &c. in various parts of the Continent. In 1866 he returned to England, and entered into partnership with his father. Amongst his numerous inventions were improvements in water meters in traction engines, and in wrought metal wheels, the spokes of which consist of hollow bars or tubes screwed into the nave or tire. The metal packing-rings which he brought out in 1872 proved of great practical importance, as they entirely removed the difficulty till then experienced in consequence of the rapid wear of cylinders when superheated steam was employed. A subject to which he devoted many years of his life was the use of very high-pressure steam; and his labours in this direction are embodied in two papers read before this Institution (Proceedings 1861, page 94; and 1877, page 117). The work upon which he was last engaged was the "Arktos" freezing apparatus; and the intense application which he devoted to maturing it was doubtless the cause of his health breaking down. As an inventor he often conducted his numerous and costly experiments with little regard to their commercial success. He died in London on 27th April 1891, in the fifty-seventh year of his age,

after an illness of nearly a year's duration. He became a Member of this Institution in 1861.

Thomas Tucker was born at Gateshead on 31st March 1849. On the death of his father in 1872, he succeeded to the management of the Turk's Head Brewery, Gateshead, which had been established by his grandfather in 1845; and though only a youth he carried on the business successfully and greatly improved it. He is believed to have been the first to adopt copper as the sole material for the utensils required in brewing, so that the beer should never touch wood until it reached the cask. He was connected with several of the local institutions, and was a member of the Town Council for some time. His death took place on 7th January 1891, at the age of forty-one. He became an Associate of this Institution in 1888.

Joseph Whitley was born at Wakefield on 17th October 1816, and as a boy was employed at Hayden's Engineering Works in that town. In 1832 he went to Leeds, and was employed at the engineering works of Messrs. Fenton Murray and Jackson. Commencing business in Leeds on his own account in 1844, he was up to his death the head of the firm of Messrs. Joseph Whitley and Co., now Whitley Partners. In 1858 he began to make improvements in metallurgical science, in the treatment particularly of iron and bronze, including the manufacture of multiple plates for the construction of ships and steam boilers, and for other purposes requiring great strength; also in the construction of moulds employed in the manufacture of spun metals and compounds of metals. At the Inventions Exhibition in 1885 he showed the spinning of liquid metals by centrifugal force, thereby attaining greater homogeneity and density and tensile strength; and he exhibited a spun roller, consisting of several layers of hard and soft iron, yet all in one solid mass, and suitable for printing and embossing. His death took place in New York on 12th January 1891, at the age of seventy-four. He became an Associate of this Institution in 1865, and a Member in 1873.

PIVOT FRICTION.

Friction Apparatus.

Plate 30.

Fig. 1. *Longitudinal Section.*

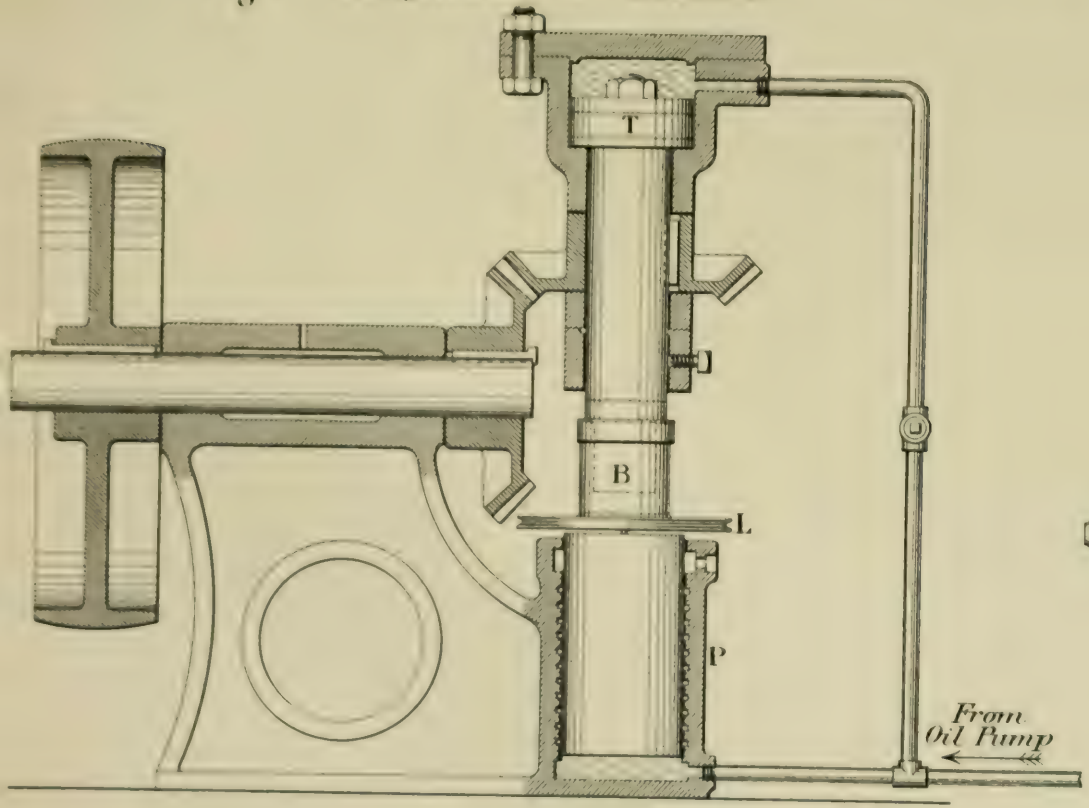
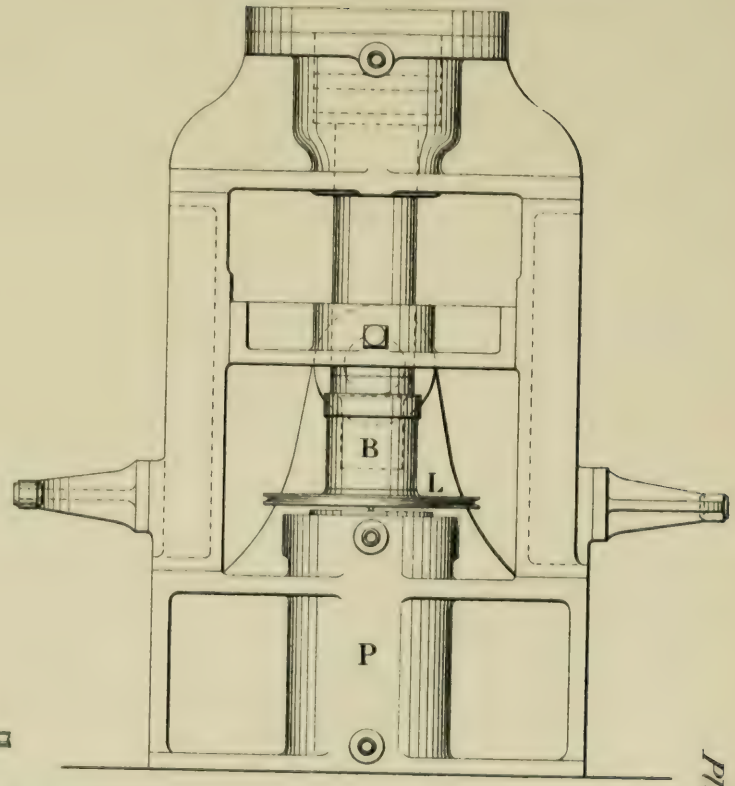


Fig. 2. *End Elevation.*



Scale 1/12th

Mechanical Engineers 1891

Inches 12 6 0 1 2 3 Feet.

Plate 30.

Friction Apparatus.

Footstep and Bearing.

Fig. 3. *Sectional Elevation.*

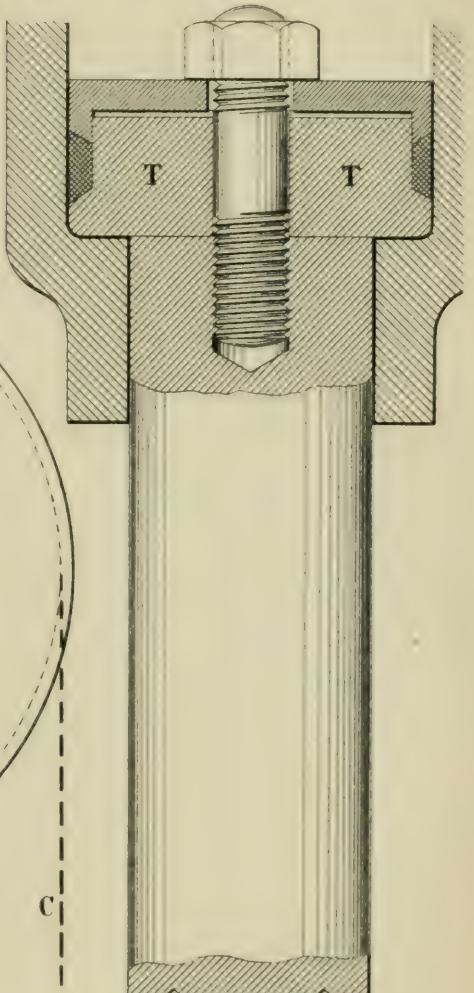


Fig. 4. *Plan of Bearing.*

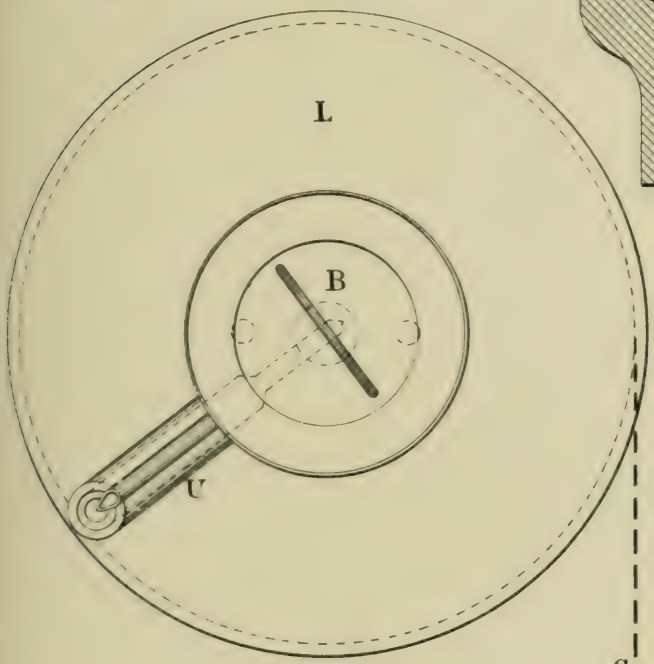


Fig. 5. *Vertical Section.*

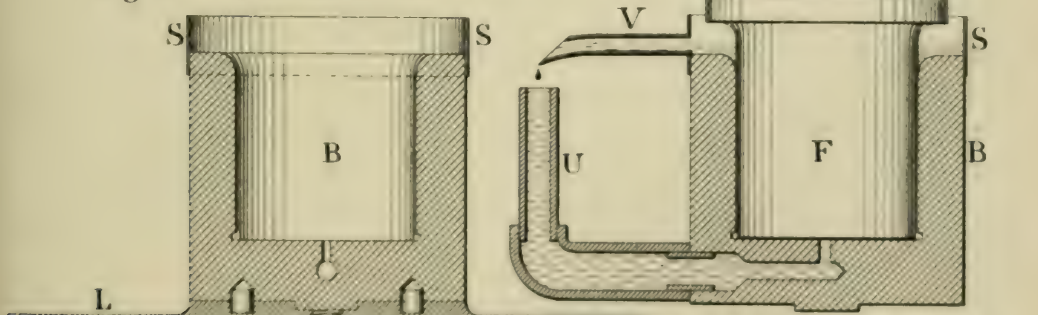
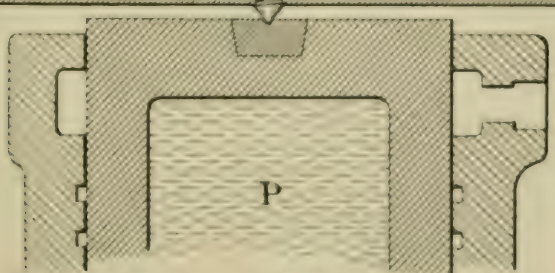


Fig. 6. *Full size.*



Mechanical Engineers 1891

Scale 1/4th

0 1 2 3 4 5 6 7 8 9 10 11 12 Inches

Steel Footstep on Manganese-Bronze Bearing.
See Tables XVI *and* XVII.

Fig. 7. *Total Friction.*

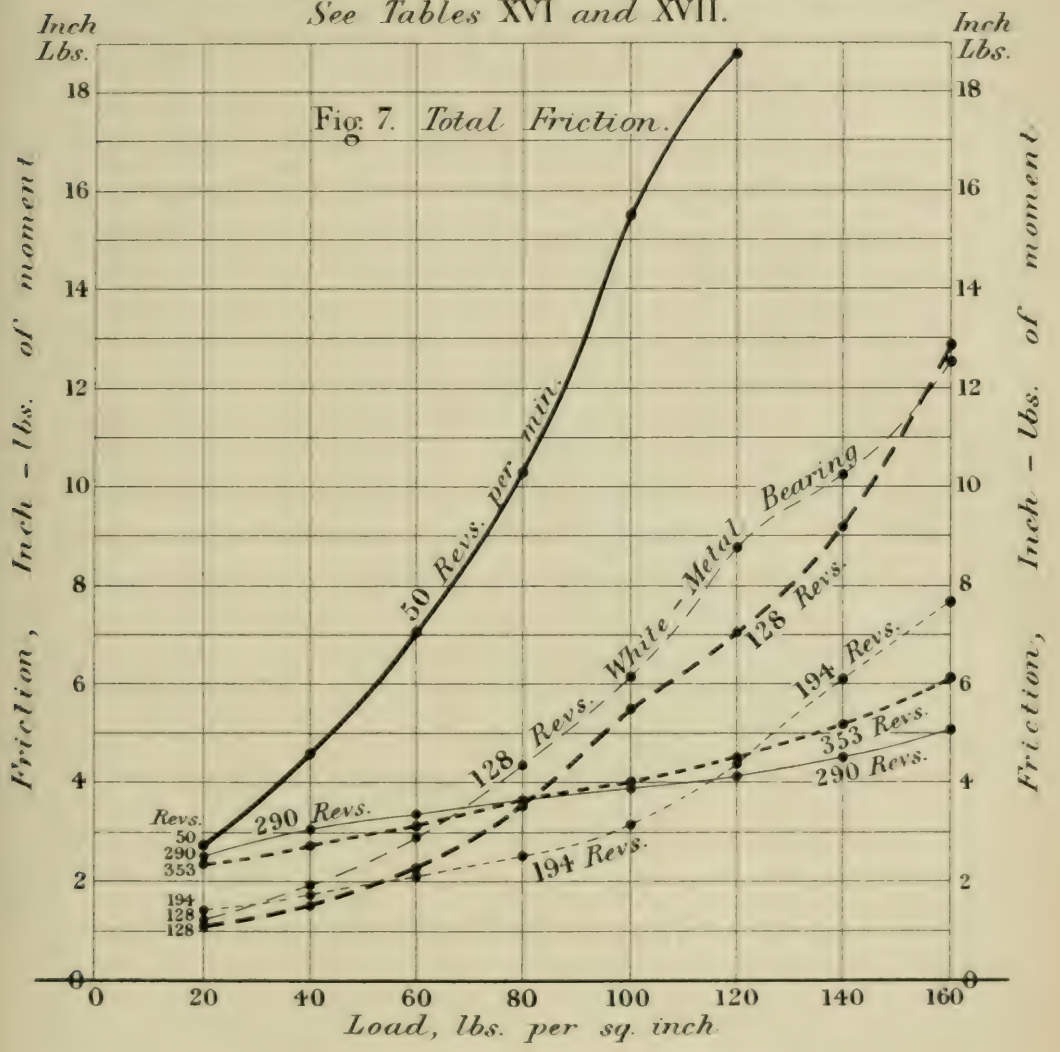
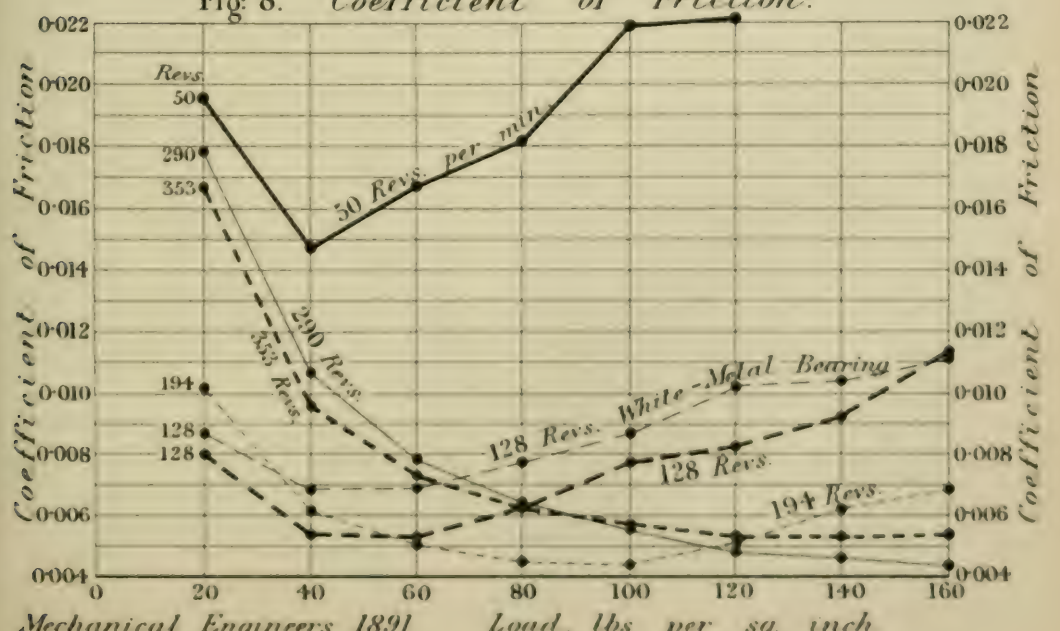


Fig. 8. *Coefficient of Friction.*



Rio Tinto Drill.

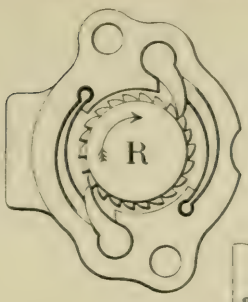


Fig. 2.

Back Cylinder-Cover.

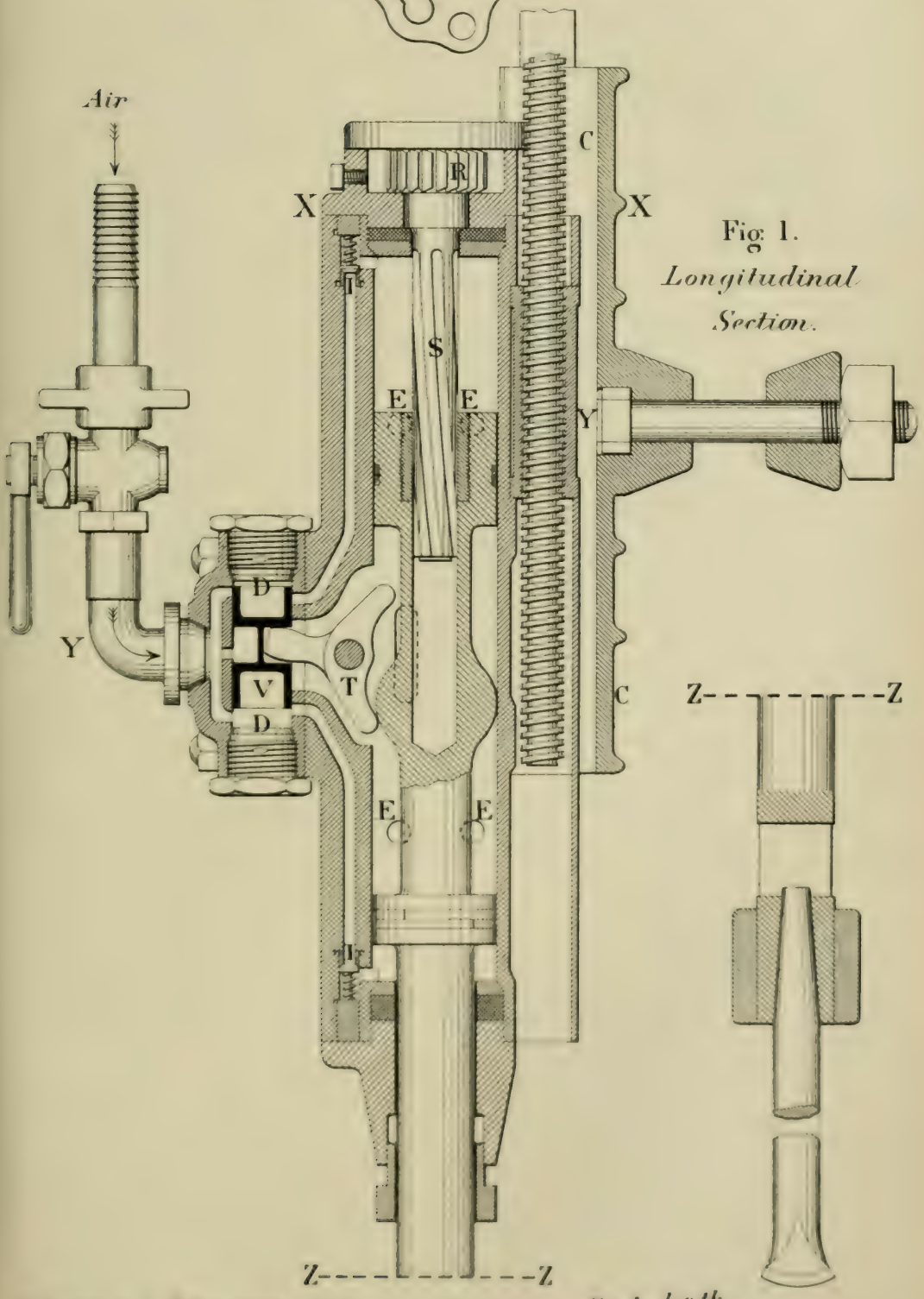


Fig. 1.

Longitudinal Section.

Mechanical Engineers 1891

Scale 1/6th

0 5 10 15 20 Inches

Rio Tinto Drill.

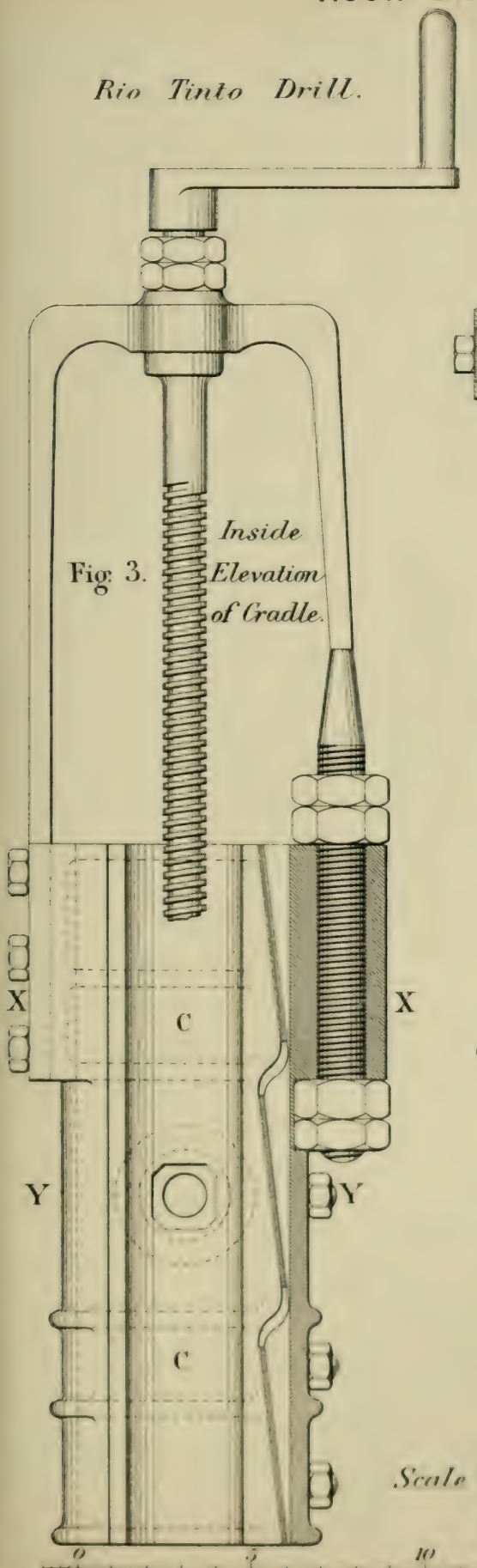


Fig. 3. *Inside Elevation of Cradle.*

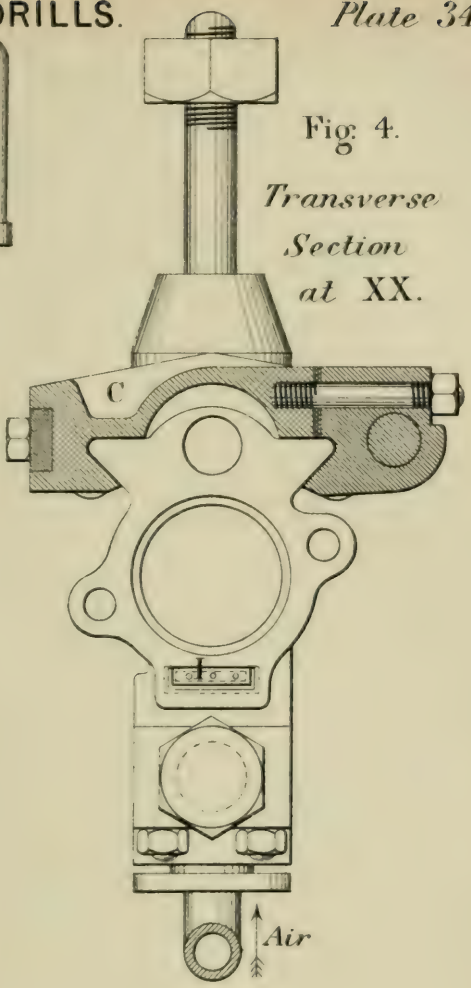


Fig. 4. *Transverse Section at XX.*

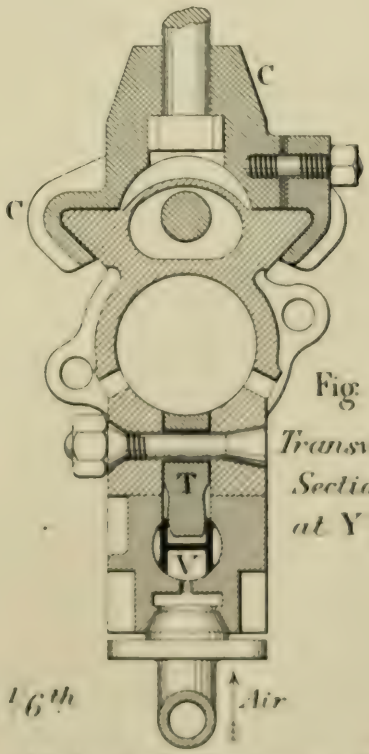
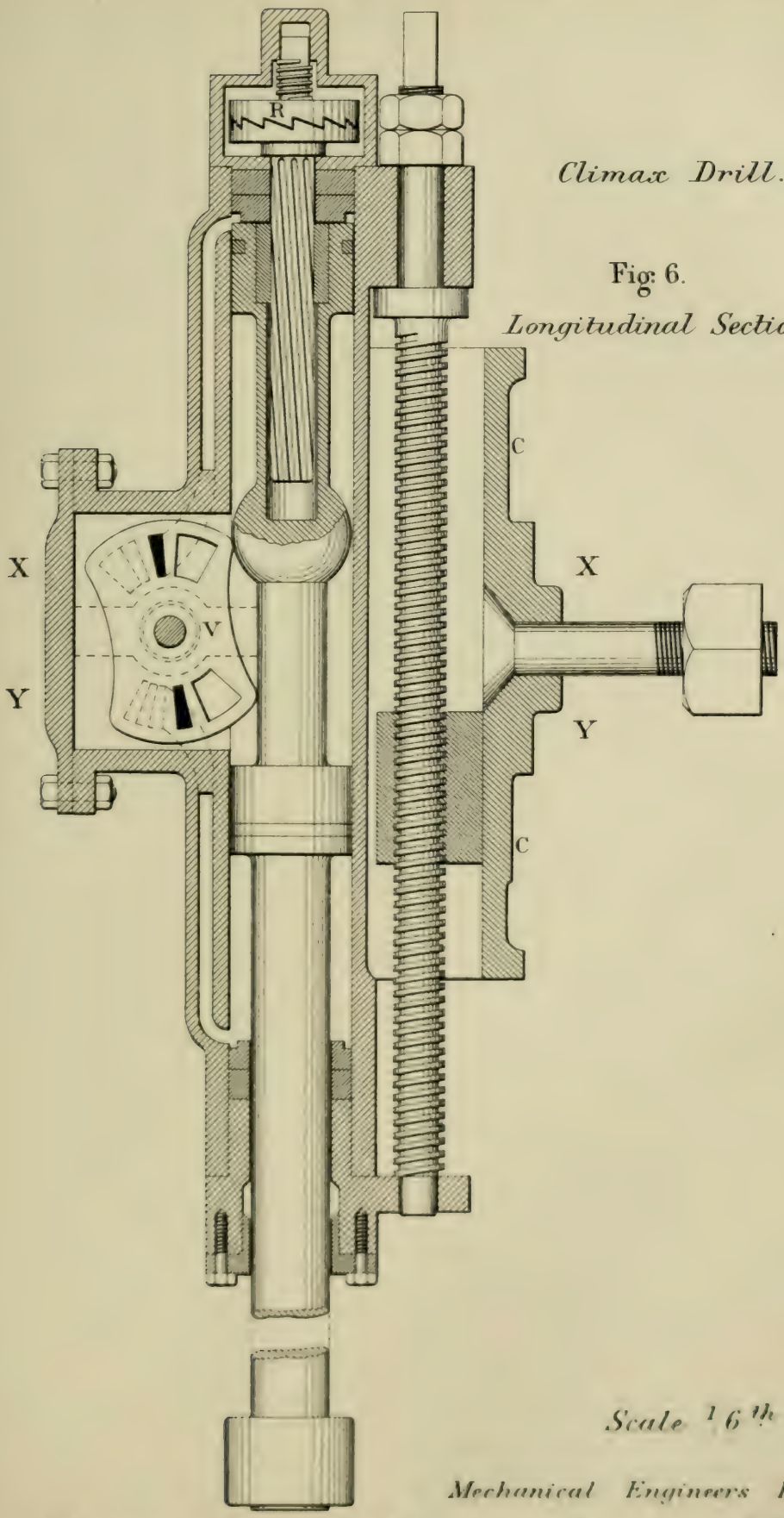


Fig. 5. *Transverse Section at YY.*

Scale 1/6th

Mechanical Engineers 1891

0 5 10 15 20 Inches



Climax Drill.

Fig: 6.

Longitudinal Section.

Scale 1 6th

Mechanical Engineers 1891

0 5 10 15 20 Inches

Climax Drill.
Scale 1/6th

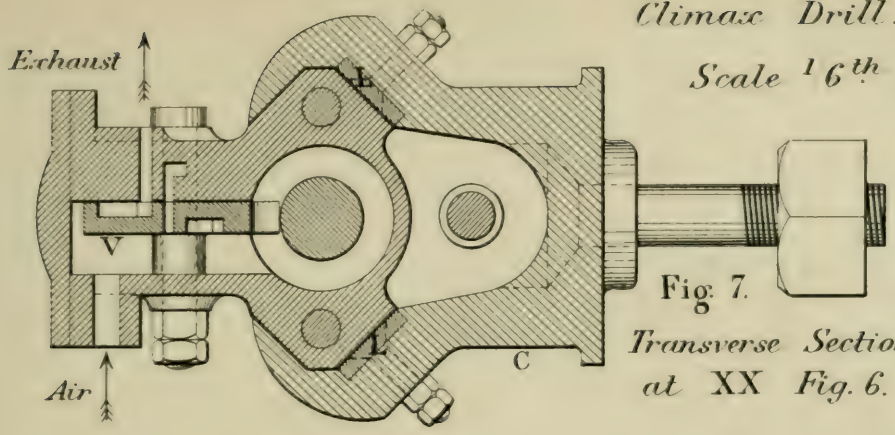
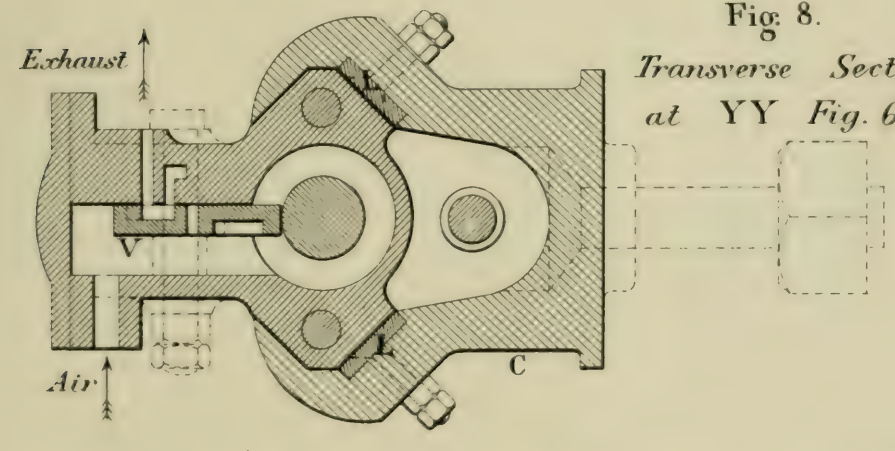


Fig. 7.
Transverse Section at XX Fig. 6.

Fig. 8.
Transverse Section at YY Fig. 6.



Longitudinal Section of Valve Chest.
Fig. 9.

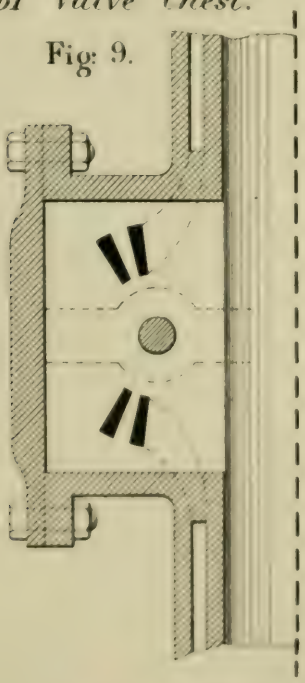


Fig. 10. *Transverse Section of Valve.*

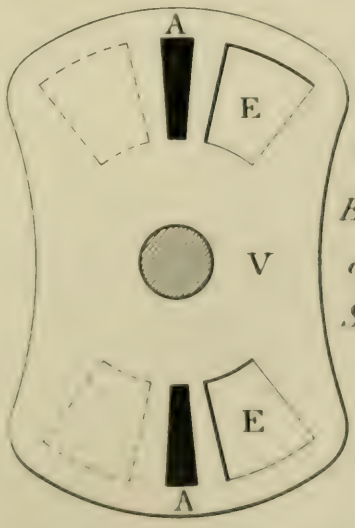


Fig. 11.
Elevation of Valve.
Scale 1/3rd

Fig. 12.

Scale 1/6th

Mechanical Engineers 1891

0 5 10 15 20 Inches

Bickle Drill.

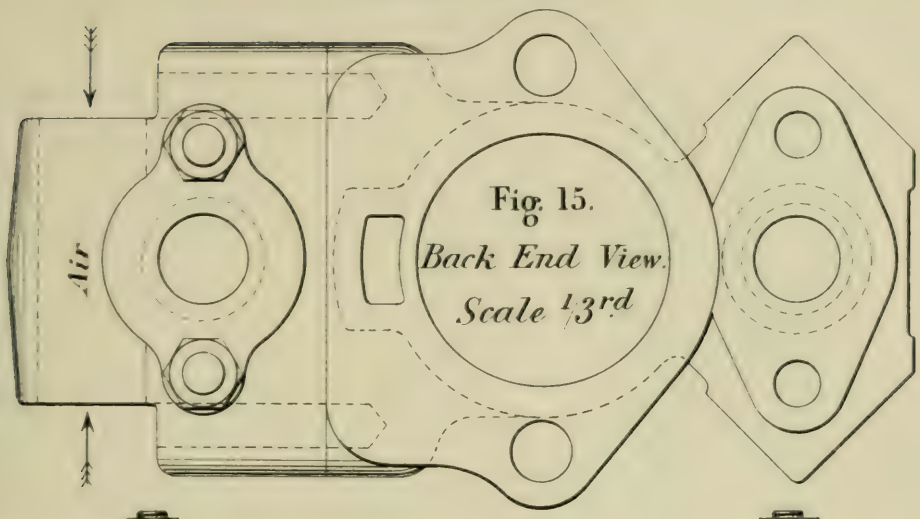


Fig. 15.
Back End View.
Scale 1/3rd

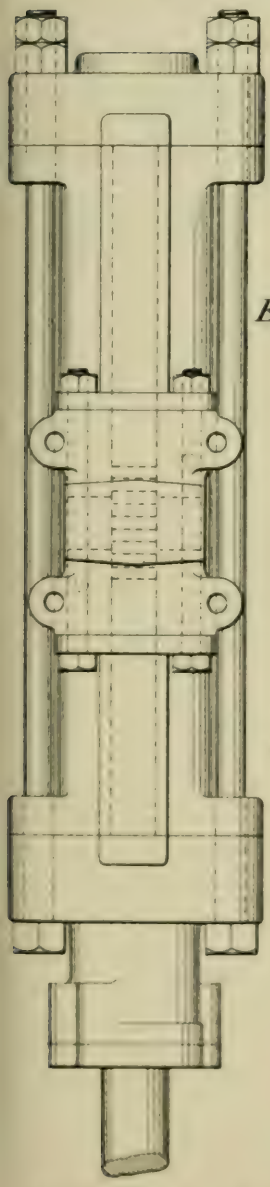


Fig. 13.
Side Elevation.

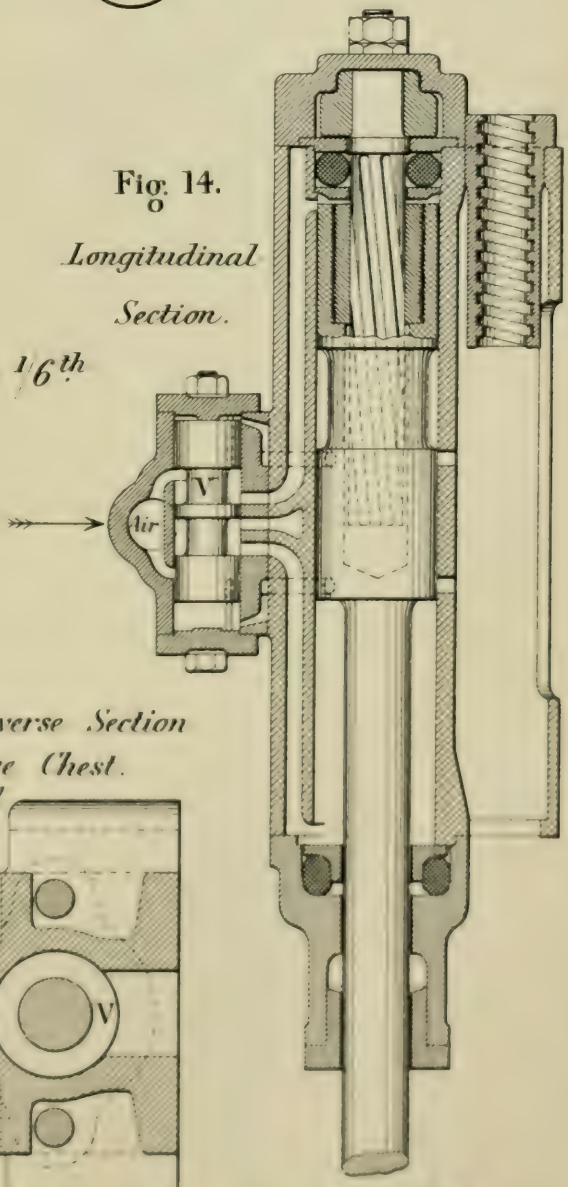
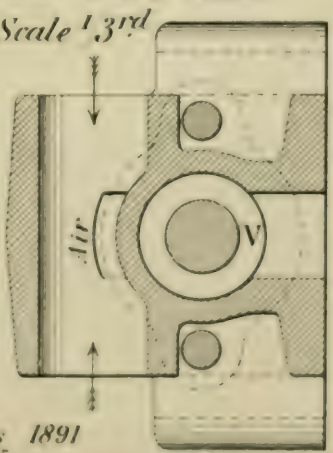


Fig. 14.
Longitudinal Section.

Scale 1/6th

Fig. 16. *Transverse Section of Valve Chest.*
Scale 1/3rd



Mechanical Engineers 1891

Scale 1/6th

0 5 10 15 20 Inches

Ingersoll - Mayne Drill.

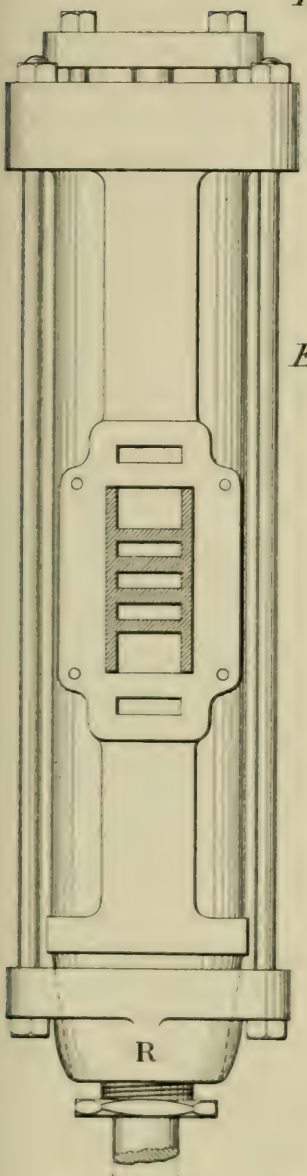
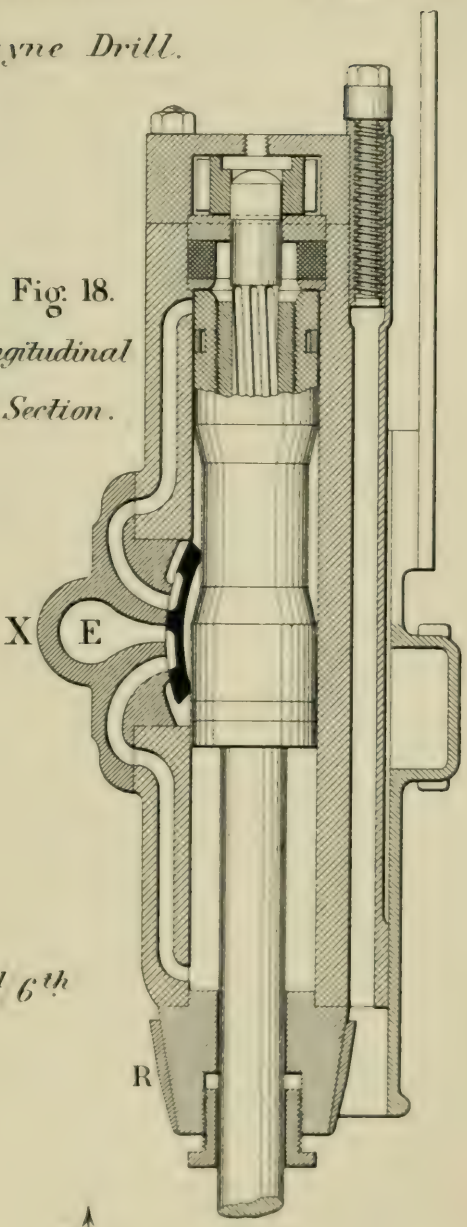


Fig. 17.
Side Elevation.

Fig. 18.
Longitudinal Section.



Scale 1/6th

Attachment of Drill.

Fig. 19.

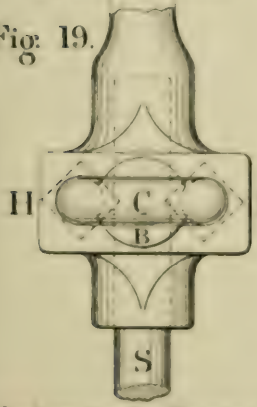


Fig. 20.

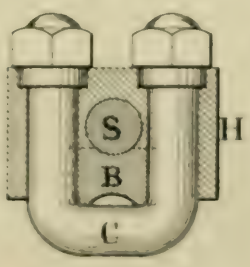
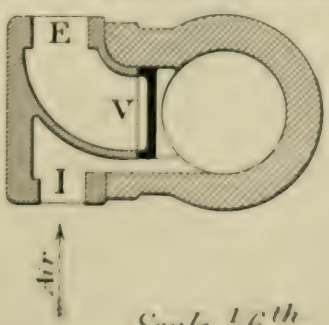
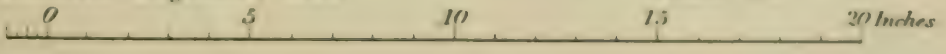


Fig. 21.
Transverse Section at X.



Mechanical Engineers 1891

Scale 1/6th



Coles Drill.

Fig. 24. Transverse Section at X X.
Scale 1/3rd

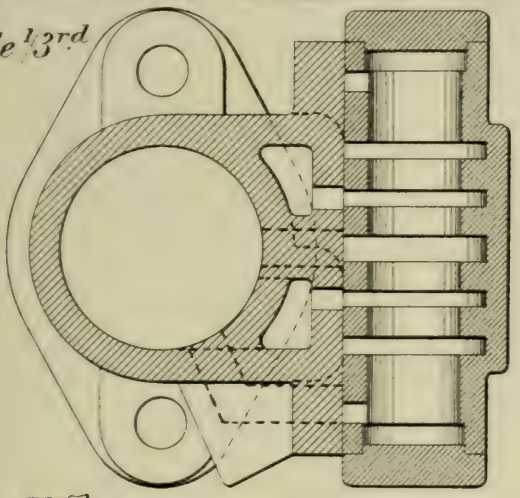


Fig. 23.
Side Elevation.
Scale 1/6th

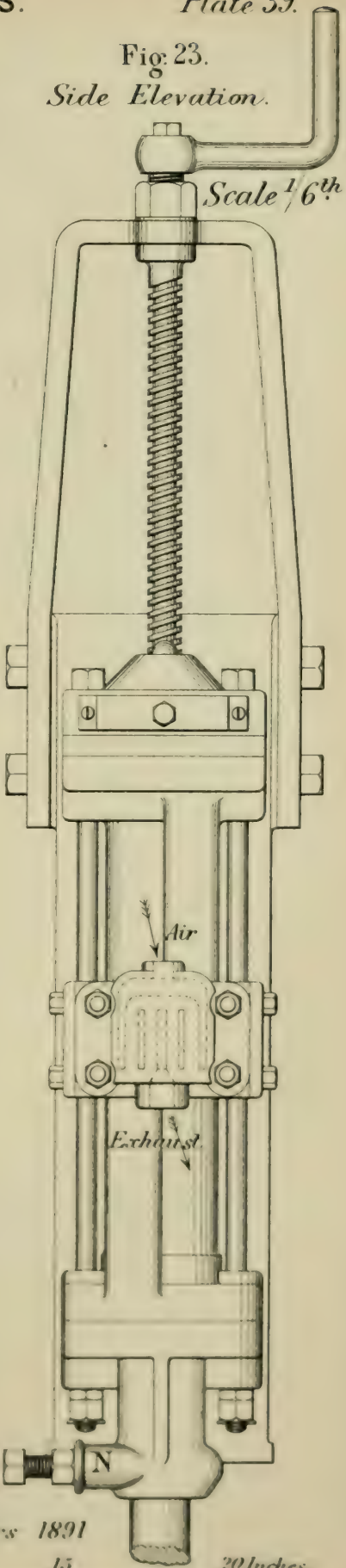


Fig. 22. Longitudinal Section.
Scale 1/6th

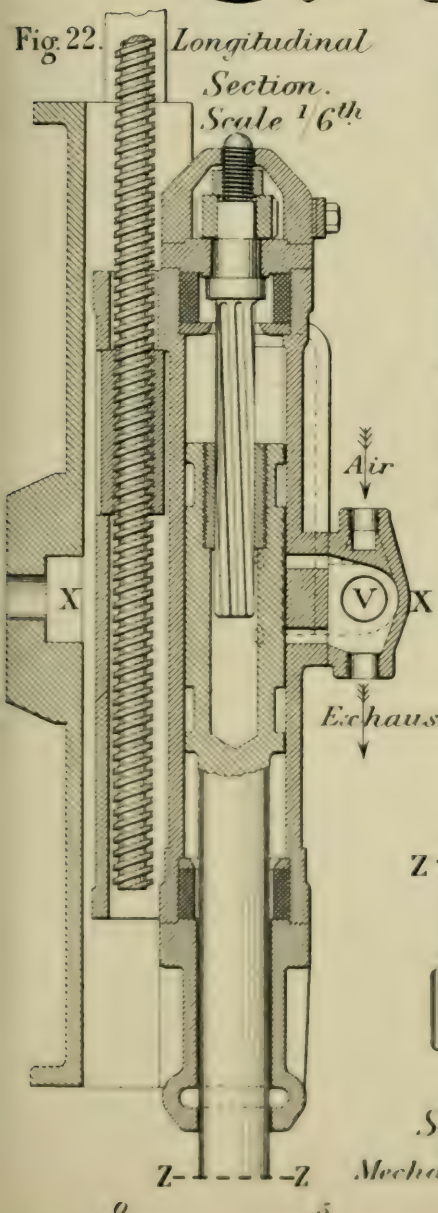
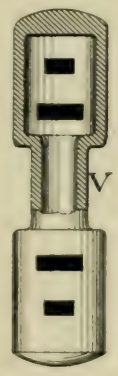
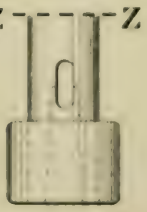


Fig. 25.
Valve.





Scale 1/6th

Mechanical Engineers 1891

0 5 10 15 20 Inches.

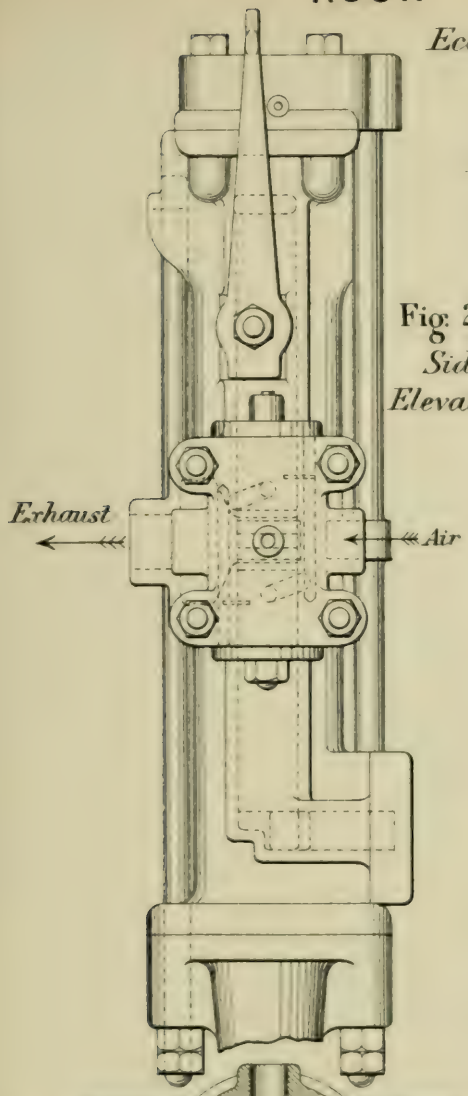
ROCK DRILLS.

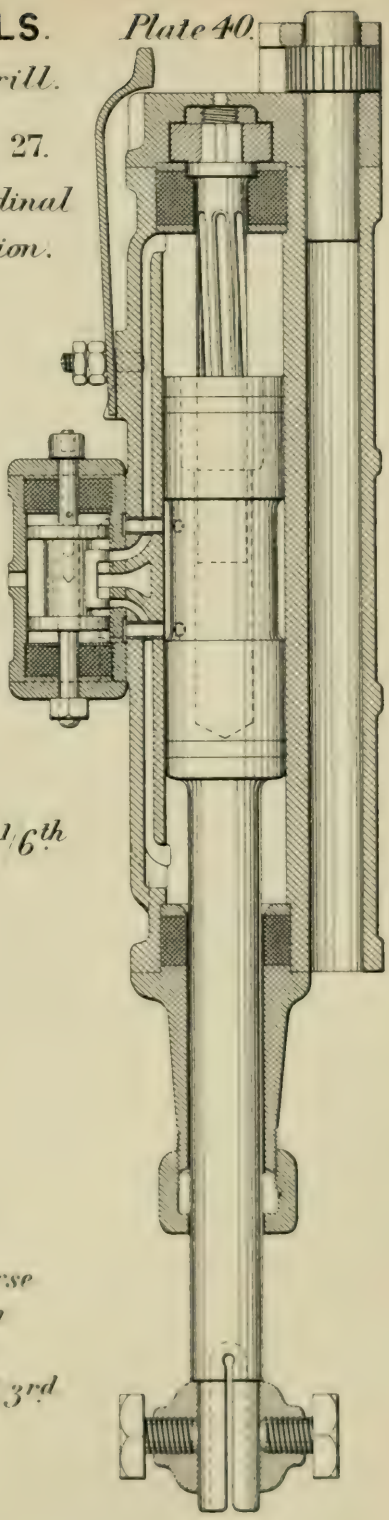
Plate 40.

Eclipse Drill.

Fig. 27.
Longitudinal Section.

Fig. 26.
Side Elevation.





Scale 1/6th

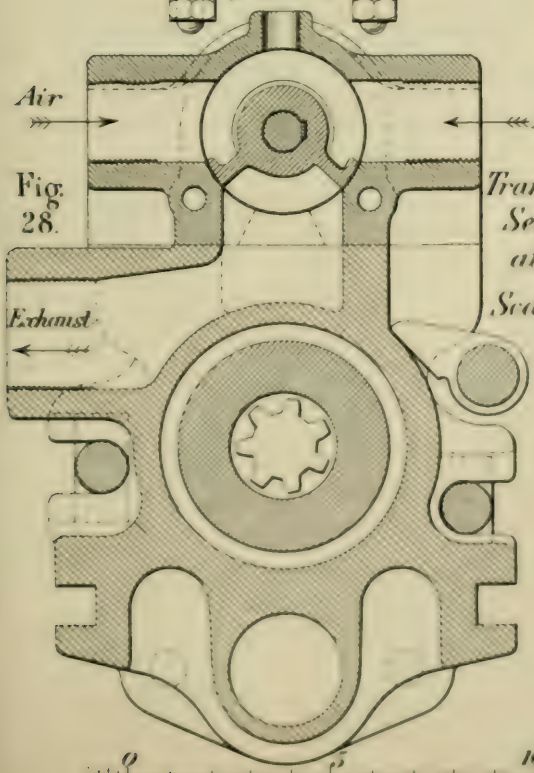
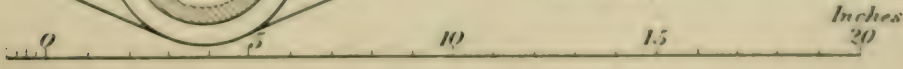


Fig. 28.
Transverse Section at X.
Scale 1/3rd

Mechanical Engineers 1891

Scale 1/6th



Ingersoll Hand-Power Drill.

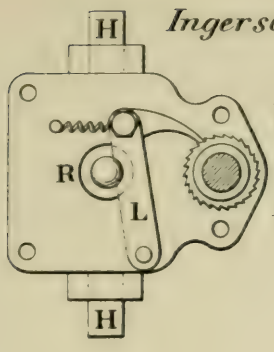


Fig. 30. *Plan.*

Fig. 31. *Cam.*

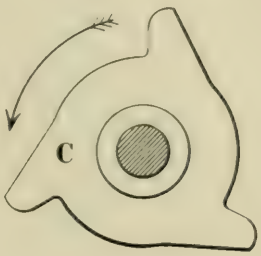


Fig. 29.

Longitudinal Section.

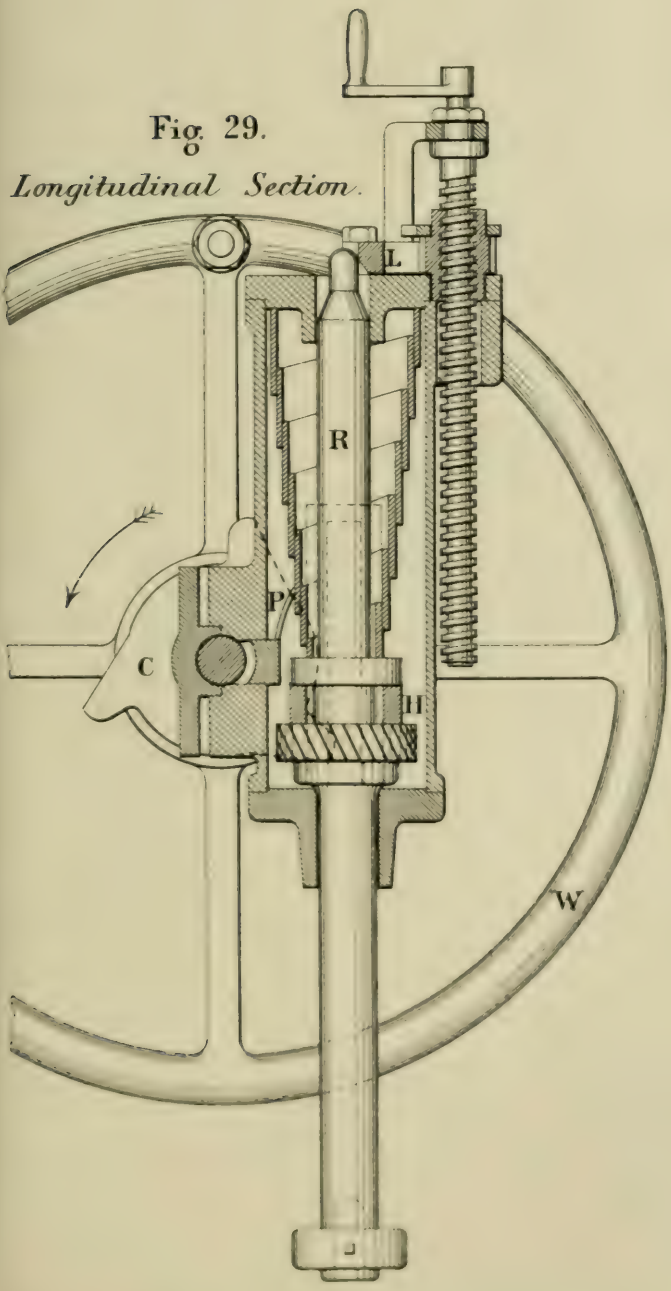


Fig. 32.

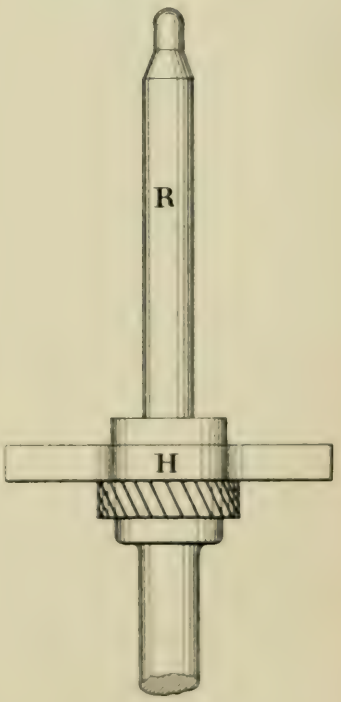
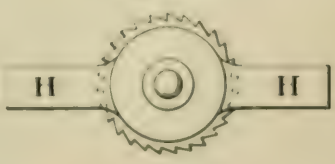


Fig. 33.



Mechanical Engineers 1891 *Scale 1/6th*

0 5 10 15 20 Inches

Ingersoll Hand-Power Drill.

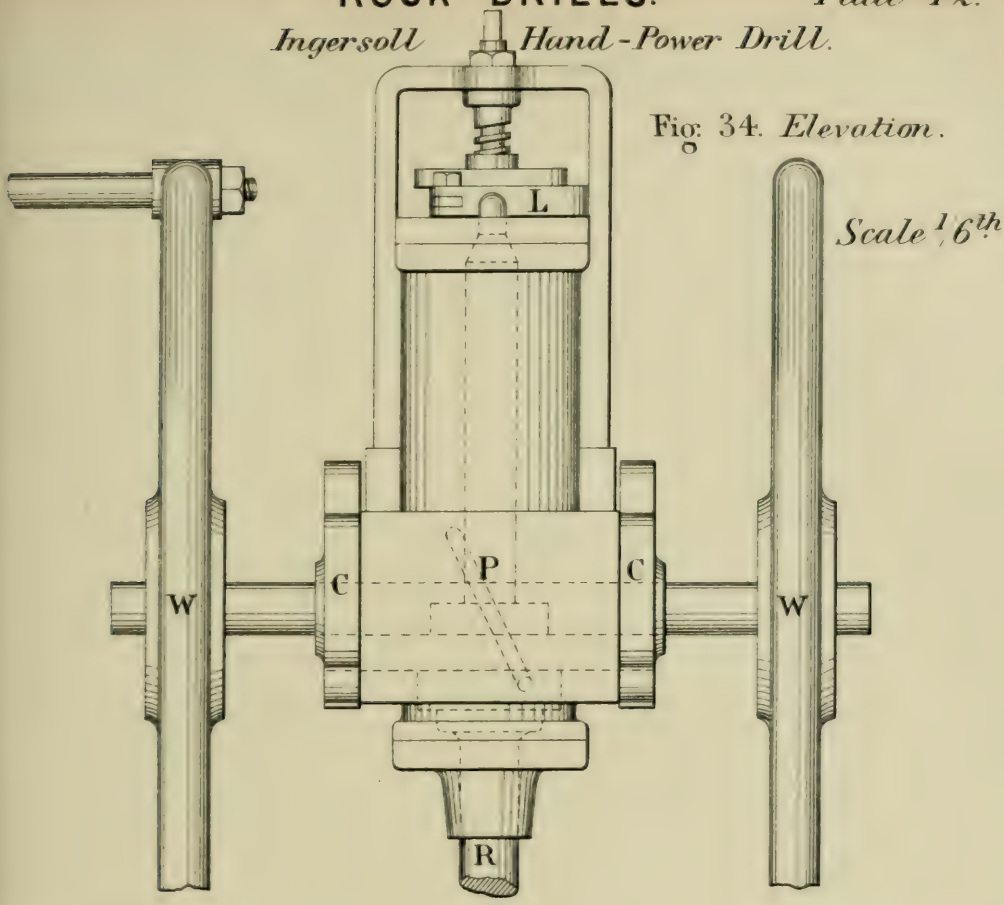
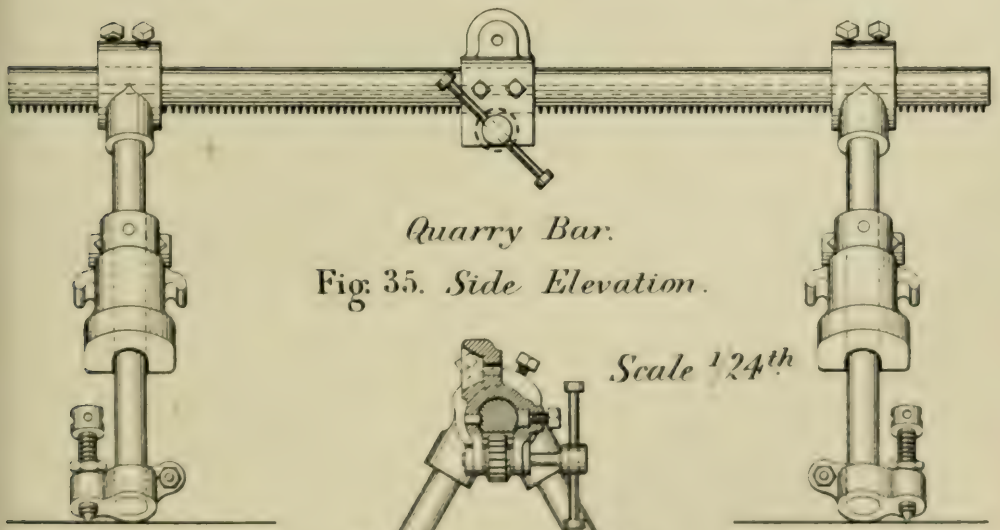


Fig. 34. *Elevation.*

Scale 1/6th



Quarry Bar.

Fig. 35. *Side Elevation.*

Scale 1/24th

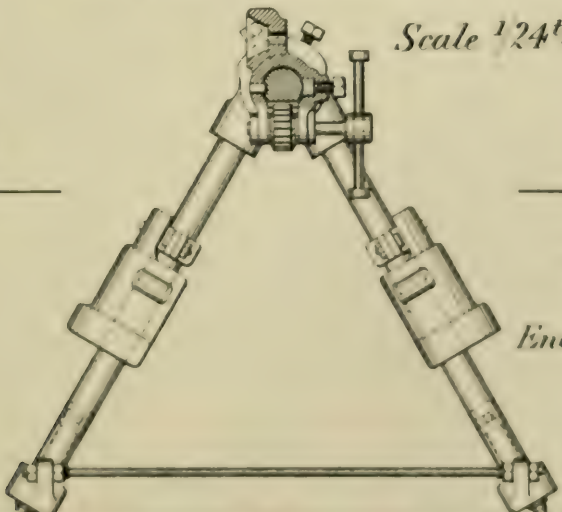
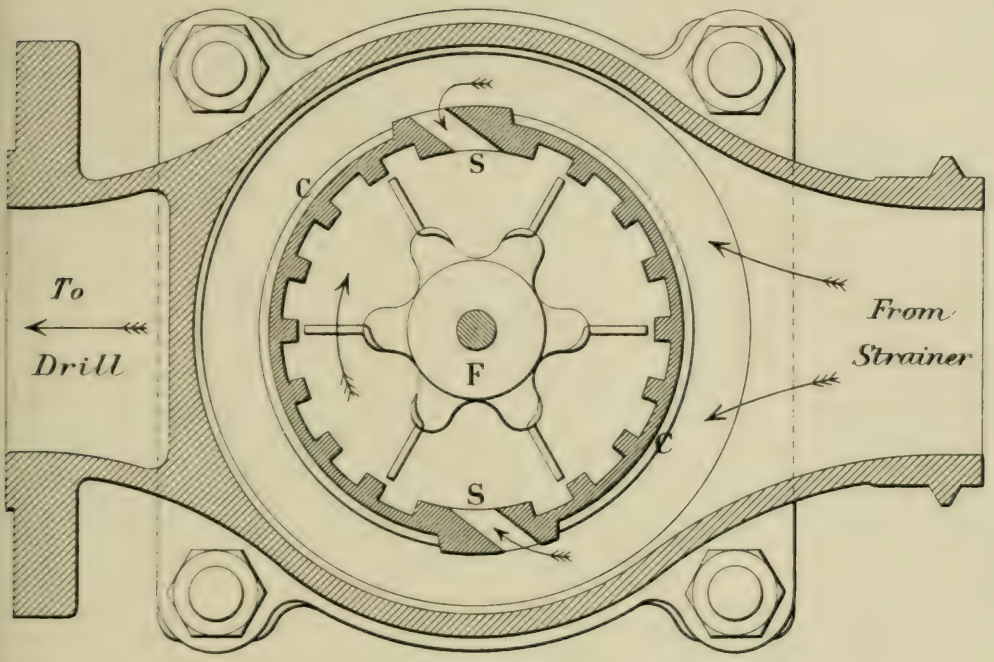


Fig. 36.

End Elevation.

Inches 12 6 0 *Mechanical Engineers 1891* *Scale 1/24th* Feet 1 2 3 4 5 6 7

Air Meter. Fig. 37. *Sectional Plan.*



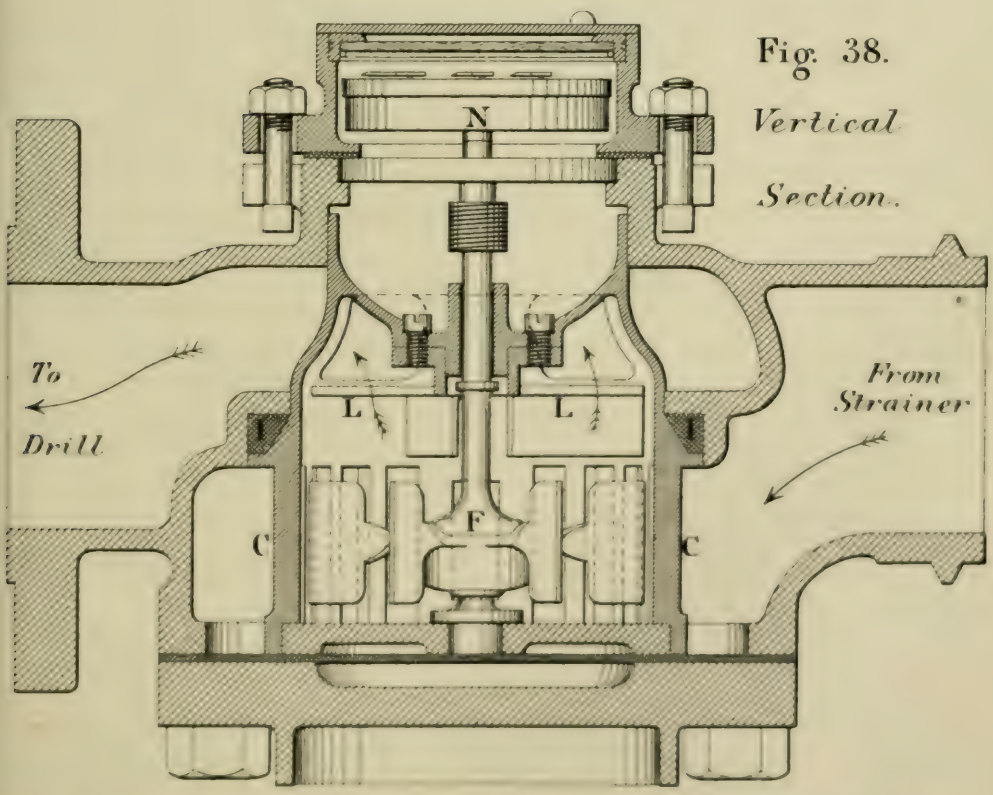


Fig. 38.
Vertical Section.

Mechanical Engineers 1891 *Scale 1/3rd*

0 1 2 3 4 5 6 7 8 9 10 inches

Institution of Mechanical Engineers.

PROCEEDINGS.

April 1891.

The later Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 30th April 1891, at Half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President said that since the last meeting they had lost by death Mr. Benjamin Walker, who had been a Member of the Institution for twenty-four years, and a Member of Council for six years. The Members he was sure would all feel with him the greatest regret at the loss of so genial a member as their late friend, and one so outspoken in the expression of his views. Although his technical knowledge might perhaps not have been of the greatest, he was to all intents and purposes a practical engineer, having been brought up in the rough school of days gone by; and at the same time he was one of those hard-headed men, who, when once they took anything in hand, never let it go until they succeeded in carrying out what they wanted. Having himself known Mr. Walker intimately for more than thirty years, his death had come to him as a very great blow. He had been a sincere old friend of himself, and a sincere friend to the Institution, always ready to do anything he could to benefit the profession. A letter of condolence had been sent to his family from the Council.

In accordance with the articles of association, for supplying the consequent vacancy amongst the Members of Council, the Council

(The President.)

had endeavoured to give effect to the wishes of the Members by appointing Mr. Edward B. Marten, who had been a Member of Council for the last six years, and whose name stood next in order in the result of the voting by the ballot lists at the last election of officers. At the next Annual General Meeting he would retire, and would then be eligible for re-election by the Members.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following forty-seven candidates were found to be duly elected :—

MEMBERS.

Marcus Allen,	Manchester.
Charles Sneath Allott,	Manchester.
Alexander Southerland Anderson,	Cawnpore.
Bernard Asplen,	Southall.
Henry Bates,	Manchester.
Arthur Edwin Battle,	Melbourne.
David Noble Bertram,	Edinburgh.
William Black,	Cardiff.
George William Blackburn,	Leeds.
Adolphus Brunner,	Munich.
Francis Dixon Bumsted,	Hednesford.
Henry Joseph Butter,	Plumstead.
Samuel John Caswell,	Kobe, Japan.
Alfred Chatterton,	Madras.
Joseph Crosland,	Southport.
Harry Bolton Daglish,	St. Helen's, Lanc.
David Duncan Esson,	Northfleet.
George Henry Firth,	Manchester.
John Drummond Frier,	Madras.
Thomas Hepburn,	Poona, India.
Arthur Hodge,	London.
Thomas Oswald Hogarth,	Swindon.
Ralph Horsfield,	Chapel-en-le-Frith.
William Field How,	London.

Henry George Jordan, Jun., . .	Manchester.
Reginald Henry Mahon, Capt. R.A.,	London.
Frederick Spencer Metcalfe, .	Burton-on-Trent.
Robert Middleton, . . .	Leeds.
Thomas Nicholson, . . .	Glasgow.
Joseph Pattison, ...	Cardiff.
Scott Paulson, ...	Johannesburg.
Thomas Alfred Reed, . . .	Cardiff.
Bartholomew Richmond Rowland, .	Manchester.
Arthur Slater Savill, . . .	Manchester.
Arthur Forbes Scott, . . .	Bradford.
Henry Sharp, ...	London.
Ernest Tetlow, ...	Hollinwood.
Albert Tilley, ...	Bilbao.
Arthur Tannett Walker, . .	Leeds.
Leonard West, ...	St. Helen's, Lanc.
Thomas Wilson, ...	Iquique, Chile.

ASSOCIATES.

George Foster, ...	Sheffield.
Francis Henry Spencer, . .	Johannesburg.

GRADUATES.

Thomas Stanley Gillatt, . .	Glasgow.
William James Hodgson, . .	Nottingham.
Matthew William Mills, . .	Heywood.
Frederick Augustus Yerbury, .	London.

The following Paper was then read and partly discussed:—

"Research Committee on Marine-Engine Trials: Report upon Trial of the Steamer Iona"; by Professor Alexander B. W. Kennedy, F.R.S., *Chairman*.

Shortly after Half-past Nine o'clock the Meeting was adjourned to the following evening. The attendance was 80 Members and 56 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Friday, 1st May 1891, at Half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The Discussion upon the Report on Marine-Engine Trials was resumed and concluded.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers, for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at Ten o'clock. The attendance was 62 Members and 37 Visitors.

The Annual Dinner of the Institution was held at The Criterion, Piccadilly, on Wednesday evening, 29th April 1891, and was largely attended by the Members and their friends. The President occupied the chair; and the following Guests accepted the invitations sent to them, though some were unavoidably prevented at the last from being present.

Institution of Civil Engineers. — Sir John Coode, K.C.M.G., President. Sir John Fowler, Bart., K.C.M.G.; Mr. James Abernethy, F.R.S.E.; Mr. Thomas Hawksley, F.R.S.; Past-Presidents. Mr. George Berkley; Mr. Harrison Hayter; Mr. Alfred Giles, M.P.; Sir Robert Rawlinson, K.C.B.; Vice-Presidents. Mr. William Pole, F.R.SS. L. & E., Honorary Secretary. Mr. James Forrest, Secretary.

Sir Frederick A. Abel, K.C.B., F.R.S., Honorary Life Member. Mr. William Cochrane, President of the North of England Institute of Mining and Mechanical Engineers; Sir William T. Lewis, President of the South Wales Institute of Engineers; Mr. Robert C. Driver, President of the Surveyors' Institution; Sir James Kitson, Bart., President of the Iron and Steel Institute; Mr. Charles F. Amos, President of the Hull and District Institution of Engineers and Naval Architects.

Mr. James S. Beale, Honorary Solicitor. Mr. Robert A. McLean, Auditor.

Professor T. Hudson Beare, F.R.S.E.; Professor D. E. Hughes, F.R.S.; Professor W. C. Roberts-Austen, C.B., F.R.S.; Mr. A. G. Ashcroft; Mr. Samuel Boswell; Mr. J. Fiddes Brown; Mr. Thomas Kennedy; Mons. Maurice Ortmans; Mr. Charles J. Wilson, F.I.C.

The President was supported by the following Officers of the Institution:—*Past-President*, Mr. Jeremiah Head; *Vice-Presidents*, Sir James N. Douglass, F.R.S., and Professor Alexander B. W. Kennedy, F.R.S. *Members of Council*, Mr. Benjamin A. Dobson, Sir Douglas Galton, K.C.B., D.C.L., F.R.S., Mr. Samuel W. Johnson, Mr. Arthur Keen, Mr. John G. Mair-Rumley, Mr. William H. Maw, Mr. William H. White, C.B., F.R.S., and Mr. J. Hartley Wicksteed.

After the usual loyal toasts had been proposed by the President, the toast of "The Houses of Parliament" was proposed by Mr. Benjamin A. Dobson, Member of Council, and acknowledged by Mr. Alfred Giles, M.P. Sir James N. Douglass, F.R.S., Vice-President, proposed the toast of "Kindred Professional Institutions," which was acknowledged by Sir John Coode, K.C.M.G., President of the Institution of Civil Engineers. The toast of "Our Other Guests" was proposed by Professor Alexander B. W. Kennedy, F.R.S., Vice-President, and acknowledged by Sir Frederick Abel, K.C.B., F.R.S., Honorary Life Member. The concluding toast of "The Institution of Mechanical Engineers," proposed by Mr. George Berkley, Vice-President of the Institution of Civil Engineers, was acknowledged by the President.

RESEARCH COMMITTEE ON MARINE-ENGINE TRIALS.

REPORT UPON TRIALS OF THE S.S. "IONA."

By Professor ALEXANDER B. W. KENNEDY, F.R.S., *Chairman.*

Since their Report of May 1890 the Research Committee on Marine-Engine Trials have had the opportunity of carrying out another trial, which will be found in some respects more complete than any of those they have made previously.

Steamer.—The steamer tested was the "Iona," owned by Messrs. Herskind and Woods of West Hartlepool, to whom the Committee are greatly indebted for all the facilities they kindly afforded for the trial, and for the obliging arrangements they made for the comfort and convenience of all on board. The "Iona" is a fine example of a modern well-decked cargo steamer with economical engines. She was built in 1889 by Messrs. William Gray and Co. of West Hartlepool, and engined by the Central Marine Engine Works of the same firm, with triple-expansion engines on three cranks working a single screw. She is a vessel of 275·1 feet length, 37·3 feet breadth, and 19 feet depth. Her depth moulded is 21 feet 10 inches, and her coefficient of fineness is 0·765. She has a double bottom of cellular construction 230 feet long, and can carry 443 tons of water ballast. Her registered tonnage is—gross 2,094 tons, under deck 1,610 tons, and net 1,348 tons; and she is classed at Lloyd's 100 A 1 (special survey). Her draft in Tyne Docks before the trial started was 20 feet 7 inches forward, and 20 feet 9 inches aft, or 20 feet 8 inches mean; but in salt water as measured by hydrometer she rose half an inch, so that the mean draft during the trial was 20 feet 7½ inches, corresponding to a displacement of 4,430 tons.

The "Iona" arrived at Middlesbrough from her voyage, on 23rd June 1890, and her engines were afterwards overhauled by their

"Iona."

makers. She subsequently went north to the Tyne, to take in a cargo of coal; and the trial was made during her outward voyage south. The steamer left Tyne Docks at 12.20 noon on 13th July 1890, and crossed the bar about 1.0 o'clock, the weather being fine with a fresh breeze. The fires had been lit since 6.0 a.m. on the previous day; and in order to get everything warmed up and the fires in normal condition, the trial itself was not started until 6.30 p.m. on 13th July, by which time the steamer was off Robin Hood Bay. The trial lasted for sixteen hours, ending at 10.30 a.m. on 14th July, when the steamer was off Yarmouth. The weather remained fine throughout, so that there was no difficulty in taking any of the usual observations. The speed of the engines was not altered during the trial, nor was the valve-gear touched or altered throughout the whole time. In addition to all the observations which had been taken on former trials, indicator diagrams were taken at intervals from the circulating and air pumps, from the first and second receivers, and from both ends of the condenser. The temperatures of the circulating water and discharge water were also noted; and the jacket-water, steam-pipe drain-water, and supplementary feed-water were each separately measured.

Engines.—The "Iona" is fitted with triple-expansion surface-condensing engines, the cylinders being placed in the order—intermediate, high, low, going from forward to aft, Figs. 27 to 31, Plates 54 to 56. The cranks rotate in the sequence — high, intermediate, low. The diameters of the cylinders are 21·88 inches, 34·02 inches, and 56·95 inches, by gauges. The piston-rods are all 5 inches diameter. There are no tail-rods. The stroke of all three cylinders is 39 inches. The high-pressure cylinder only is jacketed. Its jacket is supplied with steam from the boiler direct; under ordinary working conditions it is drained directly into the hot-well, but during the trial it was drained through a measuring tank, Fig. 27. A drain-pipe was taken from the steam-pipe, and another from the high-pressure valve-chest, and these were connected to another tank, so as to be also separately measured. The intermediate and low-pressure cylinders are not jacketed. The clearance volumes

of the cylinders are given by the makers as 12·41 and 10·11 and 7·64 per cent. of the volumes swept through by their respective pistons.

The high-pressure and low-pressure cylinders are provided with ordinary doubled-ported slide-valves, and the intermediate cylinder with a Trick slide-valve. None of the slide-valves are balanced. The valve-gear is the ordinary link-motion. There are two feed-pumps, one circulating pump, one air-pump, and two bilge-pumps, all driven by levers from the cross-head of the low-pressure cylinder. The feed-pumps are each 3 inches diameter, single-acting; the circulating pump is 10 inches diameter, double-acting; the air-pump is 17 inches diameter, single-acting; and the bilge-pumps are $3\frac{1}{2}$ inches diameter, single-acting. The stroke of all six pumps is 26 inches. The surface condenser contains 1,360 square feet of tube surface, in 475 tubes of $\frac{3}{4}$ inch external diameter and 14 feet 7 inches length between tube-plates. The screw propeller is of cast-iron, having four blades, and is 14 feet 6 inches diameter, with a mean pitch of 14 feet 6 inches and a surface of 63 square feet.

Boilers.—Steam is supplied by two single-ended steel boilers with Purves' corrugated flues, Figs. 32 to 36, Plates 57 and 58. The boilers are 13 feet 3 inches mean diameter and 10 feet long, with two furnaces each, or four furnaces in all. The total grate area was originally 52·5 square feet, each grate being 3 feet 9 inches long and 3 feet 6 inches broad; but the fire-bars have since been shortened by the length of one brick to 3 feet, so that at the time of the trial the total grate area was only 42 square feet. The total heating surface of the two boilers is 3,160 square feet, of which 2,590 square feet is tube surface. The total heating surface is therefore 75·2 times, and the tube surface 61·7 times the actual grate area. The ratios of total heating surface and tube surface to the original grate area are 60·2 and 49·3 respectively. There are in all 480 tubes, 3 inches external diameter and 6 feet $10\frac{3}{8}$ inches long between plates. The internal diameter of the funnel is 6 feet 3 inches, and its total height is 51 feet 9 inches above the level of the fire-grates. A damper is placed in the funnel at a height of

17 feet 8 inches above the level of the fire-grates. The total cross-sectional area through the tubes is 18·3 square feet, and the area across the funnel is 30·7 square feet. The net volume of the boilers is 2,680 cubic feet.

The boilers are worked under forced draught, on a plan designed by Mr. John R. Fothergill, the arrangement of which is shown in Plate 57. A fan in the engine-room, driven by an engine which during the trial received steam from the donkey boiler, forces air into a trunk extending across the front of the boilers. This air passes into the furnaces through gridiron valves placed just below the level of the fire-bars; each of these valves is made to close automatically by the lifting of the latch, whenever the corresponding furnace-door is opened, thus preventing flame and gases from being blown out from the furnace into the stoke-hold. A smaller air-trunk, branching off from the main trunk and provided with a deflecting valve, passes along the back of the boilers and admits a quantity of air through perforated plates into the combustion chamber, in the form of small streams, which mix with the gases after they have passed the furnace bridge and have been deflected to the bottom of the combustion chamber by a plate D hung at the back end of the furnace, Fig. 32. The fan is 60 inches diameter and 20 inches broad, and at 400 revolutions per minute is capable of supplying 14,000 cubic feet of air per minute at a pressure of 3½ inches water-gauge; it is driven direct by a Chandler single-acting high-speed engine, with cylinder 8 inches diameter and 7 inches stroke, developing 2·1 indicated horse-power at a speed of 180 revolutions per minute, which was the mean speed during the trial. The fan engine is usually supplied with steam from the first receiver of the main engines; but throughout the trial, as already stated, steam was supplied to it from the donkey boiler. Water gauges connected to the air trunks and ashpits were read at intervals of half an hour, and the following are their mean readings:—

Position of Gauge.	Pressure.
On air-trunk near fan	0·86 inch of water.
On air-trunk at back of boilers . . .	0·34 „ „
On ashpits, mean of four gauges . . .	0·17 „ „

"Iona."

Weights.—The total weight of the engines and boilers and all mountings, including water in condenser, pipes, and boilers, is about 202 tons, exclusive of shafting, tunnel bearings, and propeller. The following are the weights of the various parts of the machinery, boilers, and accessories, as given by the makers :—

Engines alone	64·92 tons
Shafting, tunnel bearings, and propeller . . .	26·59 tons
Engine-room auxiliaries, including donkeys, pipes, platforms, ladders, and gratings	12·16 tons
Water in condenser, pipes, and pumps . . .	1·71 tons
Boilers alone	58·60 tons
Boiler-room auxiliaries, including forced-draught gear, smoke-box, uptake, funnel, furnace gear, mountings, stoke-hold floor, boiler chocks, and ties . . .	28·49 tons
Water in boilers	35·75 tons
Total	228·22 tons

Duration of Trial.—The duration of the trial from start to finish was exactly 16 hours, or 960 minutes.

Coal Measurement.—The coal was weighed in baskets by means of a spring-balance in the stoke-hold, as in the former trials (Proceedings 1889, page 237; and 1890, pages 205, 214, and 226), about 450 lbs. at a time being put down on the floor beside each boiler. The trial was started with clean floors, and the time of first stoking from each weighed lot of coal was noted, as well as the time when each weighed lot was completely put on the grates. The line of coal consumption plots out as shown in Plate 44. As an additional check upon the coal measurement, a particular bunker was emptied beforehand, and coal enough for the trial was weighed into it off the trucks. The amount of coal so weighed amounted to 9·61 tons. At the end of the trial the quantity of coal still left in the bunker was taken out and weighed, and amounted to 2·82 tons, which, deducted from the whole quantity weighed into the bunker, gives 6·79 tons as the quantity used. As the coal weighed in detail during the trial was 6·67 tons, the difference between the two

methods of measurement was less than $1\frac{1}{4}$ per cent. of the whole quantity in the bunker.

The fires were cleaned once during the trial. The total weight of ashes, weighed after the trial, amounted to 430 lbs., which is about 2·9 per cent. of the whole fuel used.

The coal used throughout was Tyne coal from Walbottle Colliery. Coal samples were taken from the weighed lots frequently during the trial; and after a thorough mixture of all these samples, the final analyses, which have again been kindly made by Mr. C. J. Wilson, are as follows:—

	Coal as used.	Dry Coal.
Carbon	82·34 per cent.	83·97 per cent.
Hydrogen	5·47 „ „	5·58 „ „
Moisture	1·94 „ „	0·00 „ „
Ash	2·90 „ „	2·96 „ „
Nitrogen, Sulphur, Oxygen, &c., by difference	7·35 „ „	7·49 „ „
	100·00	100·00

A sample of the ashes was also collected, and has been analysed by Mr. Wilson as follows:—

Loss on ignition (=Carbon)	56·19 per cent.
Mineral matter	43·81 „ „
	100·00

The calculated calorific value of the fuel is 14,830 thermal units per lb., which corresponds to the evaporation of 15·35 lbs. of water from and at 212° Fahr., and to an equivalent carbon-value of 1·02 lb. per lb. of coal. A portion of the coal sample was also tested by Mr. L. A. Legros with a Thomson calorimeter of modified form, which gave a calorific value of 14,890 thermal units per lb. as the mean of two separate determinations; the difference between this and the value calculated from the analyses is less than half of one per cent. The total coal used was as follows:—

Port boiler	7,248 lbs.
Starboard boiler	7,701 lbs.
	14,949 lbs.

"Iona."

This amounts to 15·7 lbs. per minute, or 942 lbs. per hour, taking a total time for coal consumption of 15 hours 53 minutes, or 953 minutes, which was arrived at as follows. The last firing with unweighed coal before the trial began was at 6.25 p.m. upon the 13th July, and the last firing with weighed coal during the trial was at 10.21 a.m. upon the 14th, or an interval of 956 minutes. The first firing with weighed coal during the trial was at 6.38 p.m. upon the 13th, and the weighed coal was all burnt at 10.28 p.m. upon the 14th, which was the time of first firing with unweighed coal after the trial was over, or an interval of 950 minutes. A mean between these two intervals, or 953 minutes, has therefore been taken as the total time for coal consumption.

Furnace Gases.—Thirteen samples of the furnace gases were obtained, being collected over mercury by Mr. Wilson as the trial went on. The analyses of the samples are given in Table 9, pages 208 and 209. Some of the samples it will be seen were collected quickly, as for instance Nos. 5 and 10. The others were collected slowly over periods varying from half an hour to an hour. The differences between the specimens collected quickly and slowly, it will be seen, are not at all so great as those between different samples collected at about the same rate.

The chimney temperatures were read every half-hour with a mercury thermometer of the same description as that used in former trials (Proceedings 1890, page 218). Two Murrie pyrometers were also used alongside of the thermometer to indicate the chimney temperatures, and the readings of the three instruments agreed. The height of the thermometer above the furnace bars was about 30 feet. The average reading was 452° Fahr., the minimum being 410°, and the maximum 478°. The variations in chimney temperature are shown in Plate 44. Trial was made to see whether any alteration of temperature reading followed a change in the position of the thermometer bulb from the side to the centre of the chimney, but none could be detected. The mean air-temperature on deck was 62° Fahr.

"Iona."

The mean chimney-draft, which was measured by a U gauge-glass at the place where the furnace gases were collected, about 13 feet above the damper, was 0·25 inch of water. The funnel damper was only one-sixth open throughout the whole of the trial.

Feed-Water Measurement.—The feed-water was measured in the tanks which had been previously used in the "Colchester" and the "Tartar" trials (Proceedings 1890, page 219, and Plate 87). In the present trial each tank lasted about 15½ minutes. As already mentioned, separate tanks were used for measuring the jacket-water and the water from the steam-pipe and high-pressure valve-chest drains; and a third separate ten-gallon tank was used for measuring the supplementary feed-water, which was emptied into the bottom of the condenser at intervals, as shown in Fig. 22, Plate 51, according to the fluctuations of the water-level in the boilers. The water from the hot-well was pumped into the measuring tanks by a donkey pump, which was supplied with steam from the donkey boiler. This arrangement was adopted in order to prevent the additional load which would have been thrown upon the air-pump if it had had to deliver into the measuring tanks. The feeding of the main boilers was done entirely by the engine pumps, which drew the water from the measuring tanks. The arrangement of the measuring tanks and connections is shown in Fig. 27, Plate 54. The glands of the feed-pumps leaked considerably during the first hour and a half of the trial; but the leakage was then so far stopped that it could be neglected during the rest of the trial.

Steam was kept up in the donkey boiler for the fan engine, the donkey pump already mentioned, and the ballast donkey.

The total amount of water used was 136,820 lbs. during a total time of 953 minutes. This amounts to 143·6 lbs. per minute, or 8,616 lbs. per hour. The rate at which the feed-water was supplied, and the variations of its temperature, are shown in Plate 44.

Both at the commencement and at the end of the trial the boiler pressure was falling, as will be noticed from the diagram, Fig. 3, Plate 45, and the water-level was as nearly as possible the same; but the motion of the vessel at the end of the trial made the last

TABLE 9 (*continued on opposite page*).

IONA TRIAL.

Analyses of Funnel Gases by Volume.

No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Time of Collecting.
	Per cent.	Per cent.	Per cent.	Per cent.	p.m.
1	6·43	0·00	13·11	80·46	6.34–7.20
2	8·71	0·00	10·51	80·78	7.30–8.10
3	8·64	0·00	10·61	80·75	8.30–9.30
4	7·79	0·00	11·63	80·58	9.30–10.30
5	8·86	0·00	10·79	80·35	10.30
*					a.m.
9	8·93	0·00	9·67	81·40	2.30–3.20
10	8·15	0·00	11·17	80·68	3.30
11	7·15	0·00	11·70	81·15	4.30–5.30
12	7·06	0·00	12·51	80·43	5.30–6.30
13	8·91	0·00	10·80	80·29	6.30–7.30
14	8·85	0·00	10·87	80·28	8.0–8.30
15	8·82	0·00	10·78	80·40	9.0–9.30
16	8·28	0·00	11·07	80·65	9.40–10.15
Mean	**8·20**	**0·00**	**11·17**	**80·63**	

* Samples 6, 7, and 8 were not properly taken.

(*continued from opposite page*) TABLE 9.

Iona Trial.

Analyses of Funnel Gases by Weight.

Duration of Collecting.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	No. of Sample.
Minutes.	Per cent.	Per cent.	Per cent.	Per cent.	
46	9·57	0·00	14·20	76·23	1
40	12·85	0·00	11·28	75·87	2
60	12·75	0·00	11·39	75·86	3
60	11·54	0·00	12·52	75·94	4
2	13·06	0·00	11·57	75·37	5
					*
50	13·18	0·00	10·38	76·44	9
2	12·05	0·00	12·01	75·94	10
60	10·62	0·00	12·64	76·74	11
60	10·48	0·00	13·51	76·01	12
60	13·13	0·00	11·57	75·30	13
30	13·05	0·00	11·65	75·30	14
30	13·00	0·00	11·56	75·44	15
35	12·24	0·00	11·90	75·86	16
Mean	**12·12**	**0·00**	**12·01**	**75·87**	

and were therefore rejected as being unreliable.*

observation of water-level a little uncertain. An error of half an inch however, which is certainly more than could have occurred, would make a difference of less than 0·4 per cent. in the total feed, and might therefore be practically neglected. The variations of water-level in the boilers are shown in Fig. 23, Plate 51.

At 5.0 a.m. on 14th July samples of water were taken from both boilers, and at the same time a quantity of steam from the main steam-pipe was condensed and collected. These samples were analysed by Mr. Wilson to determine the percentage of salt present in each, and gave the following results :—

Sample.	Percentage of Salt present.
From Steam-pipe . .	0·00758 per cent.
„ Starboard boiler . .	0·351 „ „
„ Port „ . .	0·177 „ „
Mean of both boilers . .	0·264 „ „

Taking the average saltness of the water in the two boilers, this shows that the above sample of condensed steam contained 2·87 per cent. of boiler water, which figure therefore represents the amount of priming at the time when the sample was collected. It was intended to take a series of these samples throughout the trial; but unfortunately the condensing apparatus broke down, and the above sample was the only reliable one that was obtained.

The temperatures of the circulating water and of the discharge water were measured at about half-hourly intervals throughout the trial. Calculating from these observations, the mean temperature of the circulating water was 55·8° Fahr., and of the discharge water 75·5° Fahr.

Additional Water-Measurements.—The total water taken from the high-pressure jacket over a period of 910 minutes was 5,600 lbs., being at the rate of 6·15 lbs. per minute, or 4·3 per cent. of the total feed.

The total water from the steam-pipe and high-pressure valve-chest drains during 910 minutes was 800 lbs., or 0·88 lb. per minute, which is 0·61 per cent. of the total feed.

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The total amount of supplementary water was 8,302 lbs. in 953 minutes, being 8·7 lbs. per minute, or 6·1 per cent. of the total feed. The rate at which the supplementary feed-water was supplied is shown in Fig. 22, Plate 51, along with the variations of water-level in the boilers, Fig. 23.

Practically the whole of the water from the jacket and cylinder drains was returned into the feed-measuring tanks, and therefore re-pumped into the boilers.

Power Measurement.—Indicator diagrams were taken every half-hour from each end of each cylinder, as in the former trials. There were thus 32 complete sets of diagrams, or 192 single diagrams, taken in all. The indicators used were again kindly lent by Messrs. T. S. M'Innes and Co. of Glasgow, and were the same that had been in use in the trials of the "Colchester" and "Tartar" (Proceedings 1890, pages 219 and 231). The springs used were in most cases new, and had all been carefully tested before the trial. The following are the mean effective pressures in the cylinders in lbs. per square inch :—

Cylinder.	Top.	Bottom.	Mean.
High-pressure	47·98	45·32	46·65
Intermediate	20·52	20·36	20·44
Low-pressure	6·80	7·52	7·16

These pressures correspond with the following indicated horse-powers :—

High-pressure cylinder	205·6
Intermediate cylinder	221·2
Low-pressure cylinder	218·6
Total Indicated Horse-Power . . .	645·4

The maximum indicated horse-power given by any one set of diagrams was 667·9, which occurred at 8.15 a.m. on 14th July, with 61·3 revolutions per minute, and boiler pressure of 163 lbs. per square inch. The minimum indicated horse-power by any one set of diagrams was 627·5, at 7.15 p.m. on 13th July, with 61·4

revolutions per minute, and boiler pressure of 162 lbs. per square inch. In Plate 46 is given the set of diagrams nearest to the mean, which was taken at 10.45 p.m. on 13th July, with 61·5 revolutions per minute, and boiler pressure of 165 lbs. per square inch. From the 192 diagrams which were taken during the trial a mean diagram has been plotted for each of the three cylinders, and these are given in Plate 47. Eight diagrams were taken from the circulating pump during the trial, four from each end, and examples of these are shown in Fig. 14, Plate 48. The average power given by these diagrams is 12·4 indicated horse-power at the mean speed of 61·1 revolutions per minute. Six diagrams were taken from the air pump, which is single-acting; and examples of these are shown in Fig. 13, Plate 48. The average power given by these diagrams is 1·2 indicated horse-power at the mean speed of 61·1 revolutions per minute. Several diagrams were also taken during the trial from the first receiver, the indicator barrel being actuated from the cross-head of the intermediate cylinder; from the second receiver when the barrel was actuated from the high-pressure cross-head, and again when it was actuated from the low-pressure cross-head; and also from both ends of the condenser. Examples of the receiver diagrams are shown in Figs. 10, 11, and 12, Plate 48; the condenser diagrams are merely horizontal straight lines showing a mean absolute back-pressure of 1·2 lbs. per square inch. The continuous variations of boiler pressure are shown in Fig. 3, Plate 45; of cylinder mean effective pressures in Fig. 5; of horse-power in Fig. 2; and of speed in Fig. 4.

Speed.—The counter was read every half-hour. The total number of revolutions made was 58,651 in 16 hours, giving an average speed of 61·1 revolutions per minute throughout the trial. The maximum number of revolutions per minute for any half-hour during the trial was 61·8; and the minimum 59·7 revolutions. The continuous increase of total revolutions from the beginning of the trial is shown in Plate 44.

Pressures, &c.—All the pressure-gauges connected with the engines and boilers were checked by means of a standard gauge, and a

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correction allowed for where necessary. The mean barometric pressure during the trial was 29·67 inches of mercury, or 14·58 lbs. per square inch. The mean boiler-pressure was 165·0 lbs. per square inch above the atmosphere by the pressure-gauges in the engine-room. The mean pressures in the high-pressure valve-chest, first receiver, and second receiver were respectively 160·0 and 41·7 and 2·4 lbs. per square inch above the atmosphere. The mean vacuum in the condenser was 28·25 inches of mercury by gauge, which corresponds with a mean absolute back-pressure in the condenser of 0·70 lb. per square inch. The mean pressures in the first and second receivers, as measured from the indicator diagrams taken, were respectively 38·0 and 0·6 lbs. per square inch above the atmosphere; and the mean absolute back-pressure in the condenser, as measured from the diagrams, was 1·0 forward and 1·4 aft, or a mean of 1·2 lb. per square inch. The mean initial pressure in the high-pressure cylinder, as measured from the diagrams, was 142·5 lbs. per square inch above the atmosphere; and the mean vacuum in the low-pressure cylinder, as measured from the diagrams, was 12·74 lbs. per square inch, which corresponds with a mean absolute back-pressure of 1·84 lbs. per square inch in the cylinder.

Boiler Efficiencies.—The mean rate of combustion in the furnaces was 22·4 lbs. of coal per square foot of actual grate surface per hour, or 0·30 lb. per square foot of total heating surface per hour. The total amount of feed-water pumped into the boilers, as given in an earlier paragraph, corresponds with 9·15 lbs. per lb. of coal. The average temperature of the feed was 106° Fahr., and the temperature corresponding with the mean boiler-pressure was 373° Fahr.; so that each lb. of steam must have taken up (212–106) + 966 + 0·305 × (373–212) = 1,122 thermal units. The equivalent evaporation from and at 212° Fahr. was therefore 10·63 lbs. of water per lb. of coal, or 10·42 lbs. per lb. of carbon-value in the coal. The equivalent amount of heat utilised per lb. of coal would be 10,265 thermal units, or 69·2 per cent. of the thermal value of the fuel. This figure of course represents the actual boiler efficiency.

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The series of analyses of chimney gases given on page 209 enable the weight of the air used per pound of coal to be calculated. The weight of dry air per lb. of coal thus worked out amounts to 24·5 lbs., so that the total weight of furnace gases per lb. of coal would be about 25·4 lbs. These gases have been raised in temperature from 62° Fahr., the temperature of the outer air, to 452° Fahr., the mean chimney temperature. Taking the mean specific heat of the gases as 0·243, this corresponds to a loss of 2,407 thermal units per lb. of coal, or 16·2 per cent. of the whole calorific value of the fuel. In estimating the weight and specific heat of the gases, it has been assumed that the whole of the hydrogen in the fuel was burnt. No doubt this is not an entirely correct assumption, but the error due to it is very small. The loss due to the evaporation of the moisture in the fuel is so small that it may be neglected; and in no one of the thirteen analyses was any carbonic oxide found to be present in the gases. The quantity of heat not accounted for is therefore 14·6 per cent., which is mainly covered by the radiation, but includes also any losses due to unburnt carbon passing up the chimney, and to imperfect combustion of the hydro-carbons, &c.

The weight of air theoretically necessary for the complete combustion of 1 lb. of coal is 11·4 lbs. The air actually used is therefore about 2·15 times the amount theoretically required.

The weight of water evaporated from and at 212° Fahr. per square foot of total heating surface was 3·17 lbs. per hour.

The average rate of transmission of heat through the material of the boiler was 3,059 thermal units per square foot of heating surface per hour.

Coal Consumption.—The total coal burnt, namely 942 lbs. per hour, corresponds to 1·46 lbs. per indicated horse-power per hour. This is equivalent to 1·49 lbs. of carbon-value per indicated horse-power per hour.

Engine Efficiencies.—The total indicated horse-power being 645·4, and the total feed-water used per hour being 8,616 lbs., the feed-water used per indicated horse-power per hour was 13·35 lbs. The

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actual heat received by the feed-water per minute was 161,100 thermal units, or 249·6 thermal units per indicated horse-power per minute, which is 69·2 per cent. of the whole heat of combustion. The absolute engine efficiency, or ratio of the heat turned into work to the heat given to the feed-water, was 17·1 per cent.

Total Efficiency.—The combined efficiency of the boilers and engines, or ratio of the heat turned into work to the total heat of combustion of the fuel, was $0·692 \times 0·171$, which is equivalent to 11·8 per cent.

Steam from Indicator Diagrams.—The following are the results of measurements made upon the indicator diagrams taken, to ascertain the proportion of steam accounted for by them. The actual weight of feed-water used per revolution was 2·35 lbs.:—

Proportion of Steam accounted for by indicator diagrams.	Lbs. per Revolution.	Percentage of Total Feed.	Percentage in Jacket or present in cylinder as water.
Steam present in high-pressure cylinder after cut-off, when the pressure was 125·4 lbs. per square inch above the atmosphere	Lbs. 1·49	Per cent. 63·4	Per cent. 36·6
Steam present in intermediate cylinder, when the pressure was 19·4 lbs. per square inch above the atmosphere .	1·76	74·9	25·1
Steam present in low-pressure cylinder near end of expansion, when the pressure was 8·6 lbs. per square inch below the atmosphere . . .	1·39	59·1	40·9

Subsequent Trial by Chief Engineer.—After the trial above described had been carried out, the "Iona" made a voyage up the Mediterranean, and on her return journey from the island of Serpho to Rotterdam, on 15th August 1890, when the vessel was off the coasts of Tunis and Algeria, the Chief Engineer of the vessel, Mr. J. Fiddes Brown, carried out a trial on his own account. The weather was fine throughout the trial, with light head winds, but the vessel was rolling somewhat during the latter part. The mean draft during the trial was about 20 feet 9 inches.

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The duration of the trial by chronometer was 10 hours 53 minutes, or 653 minutes.

As in the Committee's trial in July (page 204), the coal was twice weighed, the difference between the two methods of weighing being only 1·2 per cent., which is accounted for by the difficulty of weighing accurately during the rolling in the latter part of the trial. The total coal used was 10,631 lbs., or 16·3 lbs. per minute.

Indicator diagrams were taken from each end of each cylinder every half-hour throughout the whole trial. Two Richards indicators were used; one was kept constantly on the high-pressure cylinder, while the other was changed between the intermediate and low-pressure cylinders. The indicators were attached to the cylinders by the usual long pipes and bends, and top and bottom diagrams from the same cylinder were taken on each paper. In this way 22 complete sets, or 66 separate papers with two diagrams on each, were obtained. The maximum indicated horse-power from any one set of diagrams was 730·0, taken at 1.0 p.m.; and the minimum from any one set was 683·5, taken at 3.30 p.m. In Plate 50 is given the set of diagrams nearest to the mean, which was taken at 4.0 p.m. on 15th August, with 64·0 revolutions per minute, and boiler pressure of 163 lbs. per square inch.

The revolutions were counted once in each quarter of an hour, and the mean of all the observations gave an average speed throughout the trial of 63·9 revolutions per minute.

The mean barometric pressure throughout the trial was 30·1 inches of mercury, or 14·8 lbs. per square inch. The mean pressures in the first and second receivers were respectively 41·5 and 1·8 lbs. per square inch above the atmosphere. The mean readings of the water-gauges connected with the forced-draught apparatus were as follows:—

Position of Gauge.	Pressure.
On air-trunk near fan	1·03 inch of water.
On air-trunk at back of boilers . . .	0·78 „ „
On ashpits, mean of four gauges . . .	0·32 „ „

The mean speed of the fan engine was 218·5 revolutions per minute, and the indicated horse-power developed was 2·6. As in

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the Committee's trial in July (page 203), steam was supplied to the fan engine from the donkey boiler. The mean temperature of the gases in the uptake of the furnace (see correction in page 238), as indicated by a pyrometer placed at a height of $6\frac{1}{2}$ feet above the level of the fire-bars, is given as 672° Fahr.

The principal results of the August trial are given in Table 10, pages 220–222, along with those of the Committee's trial; and it will be seen that these two sets of results agree remarkably well. The only essential difference between them is that in the August trial the coal is given as 1·38 lbs. per indicated horse-power per hour, whereas in the July trial it was 1·46 lbs. per indicated horse-power per hour. The same description of coal was used in both of the trials. In the August trial the feed-water was not measured, and the drain and jacket water was delivered direct into the hot-well, instead of being allowed to collect gradually in measuring tanks before being mixed with the feed-water. In consequence mainly of this, the feed-water entered the boiler at a mean temperature of 157° Fahr.; whereas in the July trial the mean feed-temperature was only 106° Fahr. The difference between the amount of heat taken up in the boiler by one lb. of water in the two trials is 4·6 per cent. of the larger amount. The difference between the two fuel consumptions is 5·5 per cent. of the larger amount. These two results strikingly corroborate each other, and show how exactly it is possible to estimate beforehand the actual saving due to the heating of the feed-water. The consumption of coal in the August trial, if calculated for the conditions under which the July trial was carried out, would be 1·45 lbs. of coal per indicated horse-power per hour. The continuous variations of boiler pressure, cylinder mean effective pressures, horse-power, and speed, during the August trial, are shown in Plate 49.

Speed of Vessel.—Besides careful measurements from the ship's chart, taken by Captain Cranston at regular intervals throughout the Committee's trial and embodied in the ship's log, a continuous registering log was employed to estimate the speed of the vessel, and the reading was noted every half-hour during the trial by the

captain or the officer on watch. The following extract from the ship's log, relating to the time of the trial, has been kindly furnished by Captain Cranston.

Time.	Headlands, &c., and Weather.	Distance in Nautical Miles.	
		By Log.	From Chart.
13 July 1890			
1.0 p.m.	Passed Shields Pier. Set log at zero. Light S.W. wind. Smooth sea.	0	0
6.0 „	Passed Whitby Light-houses. Fresh S.W. breeze. Smooth sea.	39·8	40·0
6.30 „	Off Robin Hood Bay. Trial began.	44·5	...
9.30 „	Passed Flamborough Head. Fresh S.W. breeze. Slight head sea.	69·5	70·0
14 July			
3.40 a.m.	Passed Outer Dowsing Light-vessel. Fresh S.W. breeze. Slight head sea.	122·5	123·5
4.20 „	Passed Dudgeon Light-vessel. Rising wind. Moderate sea.	128·0	130·0
7.0 „	Passed Hasborough Light-vessel. Strong S.W. wind. Slight head sea.	150·8	155·0
8.50 „	Passed Newarp Light-vessel. Strong S.W. wind. Slight head sea.	167·5	167·0
9.45 „	Passed Middle Cross Sand Light-vessel.	173·0	174·0
10.30 „	Off Yarmouth. Trial ended.	179·5	...
10.50 „	Passed Corton Light-vessel.	182·0	181·0

The distance recorded by the registering log during the trial was therefore 179·5 – 44·5 or 135 nautical miles in 16 hours, which is equivalent to a mean speed of 8·4 knots. The distance traversed by the ship during the trial as measured from the chart was 138 nautical miles, which is equivalent to a mean speed during the trial of 8·6 knots.

There is added to this report Table 10, pages 220–222, showing the leading results of the trial of the "Iona" carried out by the Committee on 13th and 14th July 1890; and beside these are placed

the corresponding figures for the subsequent trial made by the Chief Engineer on 15th August. There is also added an appendix giving a list of the Members of this Institution and others who have taken part in the Committee's trial.

Appendix.

Staff of Observers.

* Members of the Institution are marked with an asterisk.

One watch was taken by Mr. A. G. Ashcroft, along with Messrs. A. Brownsword, W. A. Cloud, W. Kennedy, L. A. Legros,* P. S. S. Pilcher, and E. C. de Segundo. The other watch was taken by Professor Kennedy,* along with Messrs. H. F. W. Burstall, H. R. J. Burstall,* J. T. Ewen, S. B. B. Hebb, J. S. Ruell, and J. H. Sharman. Mr. C. J. Wilson collected the gas samples during the whole of the trial. Mr. John R. Fothergill,* who is the Superintending Engineer for the owners, and Mr. Thomas Mudd,* the manager of the Central Marine Engine Works, were both on board; and Mr. J. Fiddes Brown, Chief Engineer of the ship, as well as his staff, gave every possible assistance in the work. The Committee are much indebted also to Captain Joseph Cranston and his officers for their courtesy throughout the whole of the operations.

TABLE 10 (*continued to page* 222).

Comparative Results of two Trials of the Steamer "Iona."

		Research Committee.	Chief Engineer.
1	Trial made by		
		1890	1890
2	Date of Trial	13 & 14 July	15 August
3	Duration of Trial . . . hours	16	10·88
4	Type of Engines	Triple	Triple
5	Cylinder diameter, high-pressure inches	J 21·88	J 21·88
6	„ „ intermediate . inches	N 34·02	N 34·02
7	„ „ low-pressure . inches	N 56·95	N 56·95
8	Stroke, length . . . . inches	39	39
9	Boilers, number of main boilers . . .	2	2
10	„ single-ended or double-ended . .	Single	Single
11	Furnaces, total number	4	4
12	Heating surface, total . . square feet	3,160	3,160
13	„ „ tubes . . square feet	2,590	2,590
14	Grate area (actual) . . . square feet	42	42
15	Total heating surface to grate area ratio	75·2	75·2
16	Tube surface to grate area . . ratio	61·7	61·7
17	Grate area to flue area through tubes ratio	2·3	2·3
18	„ „ area through funnel ratio	1·4	1·4
	Mean Pressures.	Lbs. per square inch.	
19	Mean boiler-pressure above atmosphere .	165·0	162·0
20	„ admission „ high-pressure cylinder above atm.	142·5	147·8
21	„ effective „ high-pressure cylinder	46·65	47·33
22	„ „ „ intermediate „	20·44	20·21
23	„ „ „ low-pressure „	7·16	7·96
24	„ „ „ total reduced to low-pressure cyl.	21·13	21·95
25	„ exhaust „ low-pressure cylinder below atm.	12·74	12·8
26	„ vacuum in condenser below atm.	13·88	13·76

J = Jacketed. N = Not jacketed.

(*continued from preceding page*) TABLE 10.

Comparative Results of two Trials of the Steamer "Iona."

	Trial made by	Research Committee.	Chief Engineer.
27	Revolutions per minute, mean . . revs.	61·1	63·9
28	Piston Constant, high-pressure cyl. . H.P.	4·41	4·61
29	„ „ intermediate „ . H.P.	10·82	11·32
30	„ „ low-pressure „ . H.P.	30·54	31·93
31	Indicated horse-power, high-p. „ I.H.P.	205·6	221·0
32	„ „ inter. „ I.H.P.	221·2	231·7
33	„ „ low-p. „ I.H.P.	218·6	255·0
34	„ „ mean total I.H.P.	645·4	707·7
35	Coal burnt per minute . . . lbs.	15·7	16·3
36	„ „ per hour . . . . lbs.	942	978
37	„ „ per square foot of actual grate area per hour lbs.	22·4	23·3
38	„ „ per square foot of total heating surface per hour lbs.	0·298	0·310
39	„ „ per indicated horse-power per hour lbs.	1·46	1·38
40	Carbon-value of 1 lb. of coal as used . lbs.	1·02	...
41	„ „ equivalent per indicated horse-power per hour lbs.	1·49	...
42	Feed-water per minute . . . lbs.	143·6	...
43	„ „ per hour . . . . lbs.	8,616	...
44	„ „ per square foot of total heating surface per hour lbs.	2·73	...
45	„ „ per lb. of coal . . . lbs.	9·15	...
46	„ „ per lb. of coal from and at 212° F. lbs.	10·63	...
47	„ „ per lb. of carbon-value from and at 212° F. lbs.	10·42	...
48	„ „ per indicated horse-power per hour lbs.	13·35	...
49	Calorific value of 1 lb. of coal as used, Th. U.	14,830	...
50	Percentage of line 49 taken up by feed-water per cent.	69·2	...
51	„ „ „ „ carried away by furnace gases p. cent.	16·2	...
52	„ „ „ „ lost by imperfect combustion per cent.	0·0	...
53	„ „ „ „ used in evaporating moisture in coal p. c.	0·0	...
54	„ „ „ „ unaccounted for p. c.	14·6	...

TABLE 10 (*concluded from page* 220).

Comparative Results of two Trials of the Steamer "Iona."

	Trial made by	Research Committee.	Chief Engineer.
55	Heat taken up by feed-water per min., Th. U.	161,100	...
56	„ turned into work per minute Th. U.	27,590	30,250
57	„ taken up by feed-water per indicated horse-power per minute, Th. U.	249·6	...
58	Efficiency of boiler (line 50) . per cent.	69·2	...
59	„ of engine (line 56 ÷ line 55) p. c.	17·1	...
60	„ of engine and boiler combined (line 58 × line 59) per cent.	11·8	...
61	Mean velocity of steam through water-surface in boilers per minute feet	1·61	...
62	Space occupied by boilers per I.H.P., cub. ft.	4·15	4·15
63	Weight of engines, boilers, &c., with water, per I.H.P., tons	0·31	0·31
64	Clearance volume, high-p. cyl. per cent.	12·41	12·41
65	„ „ inter. „ per cent.	10·11	10·11
66	„ „ low-p. „ per cent.	7·64	7·64
67	Clearance surface, high-p. cyl. square feet	12·75	12·75
68	„ „ inter. „ square feet	29·14	29·14
69	„ „ low-p. „ square feet	49·5	49·5
70	Speed of vessel, mean, during trial knots	8·6	9·0
71	Mean temperature of outer air. . Fahr.	62°	91°
72	„ „ „ chimney gases. Fahr.	452°	[672°]*
73	„ „ „ feed-water . Fahr.	106°	157°
74	„ „ „ boiler steam . Fahr.	373°	371°
75	„ „ „ circulating water, Fahr.	55·8°	78·6°
76	„ „ „ discharge water, Fahr.	75·5°	94·4°
	Forced-draught Pressures.	Inch of water.	
77	In casing, near fan	+0·86	+1·03
78	In casing, at back of boilers . . .	+0·34	+0·78
79	In ashpits, mean of four gauges . . .	+0·17	+0·32
80	In funnel	−0·25	...

* Indicated by a pyrometer in uptake of furnace. [See correction in page 238.]

Discussion.

Professor Kennedy hoped that the importance of the figures given in the Research Committee's present report might be sufficient to justify or overbalance its unavoidable dryness and stiffness for reading. It was of course the business of the Committee simply to state the facts and figures obtained, and not to endeavour to make the report more interesting by comments upon the trial.

With regard to the apparatus used for measuring the priming (page 210), which was simply an arrangement of a small surface-condenser, he had made since the trial a more permanent copy of it, and had found that it worked exceedingly well, giving results which were very easily got at.

In the diagrams taken from the two receivers, Figs. 10 to 12, Plate 48, it was a mistake for the area enclosed by the two curves to be shaded, as though they were indicator diagrams from the steam cylinders. The mean pressure marked on each diagram represented the mean pressure in either receiver, in Figs. 10 and 11 above the atmosphere and in Fig. 12 below the atmosphere, as simply measured from the two curves that were taken in one complete revolution; it had nothing to do with the area of the figure, and there was no meaning in shading the area between the two curves, which made them look as though they were cylinder indicator diagrams. [This has now been rectified by the omission of the shading in Figs. 10 to 12.] As it was over equal intervals of time that the mean pressure was wanted, it was evidently necessary to allow for the angle of the crank; and it would be noticed that in these three diagrams the figures representing the percentages of the half revolution were not spaced at equal distances apart, as they would be for the stroke of the piston, but the subdivisions were marked to correspond with equal angles of the crank, neglecting the obliquity of the connecting-rod. The mean of the two ordinates at each of these subdivisions was then taken for arriving at the mean pressure throughout the entire revolution.

In Table 10, appended to the report, the further information asked for in the previous discussion had been added as far as possible.

(Professor Kennedy.)

More particulars no doubt might still be wanted, which he was sure would be given with great pleasure, so far as the desired information was available. The report of the Committee's trial was made considerably more interesting by the fact that the chief engineer, Mr. Brown, whom he was glad to see present, had been able since to carry out a trial of his own, which he had done with great care and accuracy; and in coal consumption per indicated horse-power per hour this subsequent trial, so far as it went, gave results remarkably close to those which had actually been obtained in the Committee's trial. This was a highly interesting matter, because the chief engineer's trial had been carried out independently during the course of an actual voyage.

Mr. John R. Fothergill, superintendent engineer for the owners of the "Iona," drew attention to the deflector plate D hung at the back of the furnace, Fig. 32, Plate 57, the object of which was to deflect the gases after they had passed over the bridge, so that they were thrown down to the bottom of the combustion chamber; and as the air which came in through the nozzle at the back of the chamber was not admitted in a stream, but was subdivided into a number of jets, it had not a chilling effect, but was taken up by the gases and thoroughly mixed. By this means, as was shown by the analysis of the gases in Table 9, very complete combustion was obtained of the gases in the combustion chamber, where it was better to have the heat developed. If there were an intense local heat in the furnace, the probability was that it might do harm there; and his experience was that, by getting the complete combustion in the combustion chamber, better results were obtained in all respects, without any risk of starting the boilers to leak.

In boilers worked as these were with forced draught, it might perhaps seem surprising that the ashpit pressure was so low as only 0·17 inch of water (page 203). The explanation was that the steamer left port with most excellent coal, forming very little clinker, so that the fires were cleaned only once during the whole trial (page 205). With this coal indeed he had found that it was not necessary to clean the fires at all; and he somewhat regretted that they had been

cleaned even that once in the trial, as the grate area was perfectly clean, and no clinker had been formed; and the fires were not thick, because the grate area was somewhat large for the quantity of coal burnt, which amounted to only 22·4 lbs. per square foot of grate per hour, whereas the quantity usually burnt was about 25 or 26 lbs. Thus the air was passing up through the fire more rapidly in the trial than it would do under ordinary working conditions on a voyage, where the fires got somewhat dirty, and where there would therefore be a higher pressure in the ashpit; and this really accounted for the somewhat large quantity of air supplied to the furnace. It would accordingly be noticed that in the trial made by the chief engineer the pressure in the ashpit had gone up to 0·32 inch of water (page 216), which would be about the average pressure used in the regular voyages. In the trial the fan was running slowly, at only 180 revolutions per minute; its ordinary speed at sea was 220 revolutions. But although it was running slower in the trial, it would be seen that the quantity of air had been exceptionally large. With less air the combustion of the gases might not have been quite so complete, but he thought the boiler efficiency would have been equal, if not greater, because less heat would have been lost by passing away with the excess of air.

In Tables 11 and 12 (pages 226–7) were given the general commercial results as regarded coal consumption in four voyages made by the "Iona" during the year November 1889 to November 1890: the first and second were Indian voyages, and the third and fourth Mediterranean. The Committee's trial had been made at the beginning of the third voyage, in which it would be seen that practically no coal was received abroad, that is at ports out of the United Kingdom; and the average consumption during the whole voyage was 1·10 lbs. per indicated horse-power per hour. The results of the three other voyages, when similarly worked out and when 10 per cent. was deducted from all the coal received abroad, came remarkably close to the same consumption, namely 1·41 and 1·39 and 1·39 lbs. These figures he thought were highly interesting as showing that the trial itself had not been conducted under exceptional or special circumstances, but that the whole history of the ship through

TABLE 11.—*Particulars of four Voyages of S.S. "Iona."*

Voyage.	Date.	Passage. O = Outwards. H = Homewards. *See foot-note to Table 12.*		Loaded or Light.	Days steaming.	Draught. Ft.	Draught. Ins.	Mean Draught. Ft.	Mean Draught. Ins.	Distance steamed. Knots.	Mean Speed. Knots.	Proportional Distance Loaded to Light.
1	1889-90 November to February	Tees to Bombay	O	Loaded	34·79	20	2	20	6	12,574	7·55	23·50 to 1
		Kurrachee to Bristol	H	„	34·52	20	10					
		Bombay to Kurrachee	O	Light	2·29	9	3	9	3	535	9·17	
		Bristol to Cardiff	H	„	0·14	9	3					
					71·74					13,109	7·61	
2	1890 March to June	Cardiff to Colombo	O	Loaded	33·33	20	6	20	1½	14,014	8·07	13·67 to 1
		Cuddalore to Marseilles	H	„	29·77	19	3					
		Carthagena to Tees	H	„	9·20	20	7					
		Colombo to Cuddalore	O	Light	2·45	11	3	10	5½	1,025	9·42	
		Marseilles to Carthagena	H	„	2·08	9	8					
					76·83					15,039	8·15	
3	1890 June to September	Tyne to Savona	O	Loaded	11·75	20	7½	20	8	5,305	8·72	3·38 to 1
		Serpho to Rotterdam	H	„	13·58	20	9					
		Tees to Tyne	O	Light	0·16	10	0	9	11½	1,568	10·27	
		Savona to Serpho	O	„	3·89	10	0					
		Rotterdam to Cardiff	H	„	2·31	9	10½					
					31·69					6,873	9·03	
4	1890 September to November	Cardiff to Leghorn	O	Loaded	10·06	20	6	20	7½	5,579	7·61	2·59 to 1
		Ibrail to Rotterdam	H	„	20·47	20	9					
		Leghorn to Ibrail	O	Light	7·22	10	4	9	10	2,150	9·04	
		Rotterdam to Cardiff	H	„	2·68	9	4½					
					40·43					7,729	7·96	

TABLE 12.—*Consumption of Coal in four voyages of S.S. "Iona."*

Voyage.	Mean Revolutions per minute.	Mean Indicated Horse-Power.	Coal received.		Coal Consumption, less 10 per cent. on proportion received abroad.			
			At home.	Abroad.	Total for all purposes.	For steaming only.		
						Total.	Per day.	Per I.H.P. per hour.
	Revs.	I.H.P.	Tons.	Tons.	Tons.	Tons.	Tons.	Lbs.
1	60·85	641·2	296·40 North country	544 Welsh	764·00	699·5	9·75	1·41
2	61·27	648·4	389·80 Welsh	498 Welsh	839·00	745·8	9·71	1·39
3	62·93	677·6	370·05 North country	15 other sorts	395·55	323·55	10·21	1·40
4	59·81	623·0	294·80 Welsh	120 Welsh 45 other sorts	448·50	377·3	9·33	1·39

Voyage 1.—New ship; bottom painted with ordinary paint. Dry-docked at Cardiff; bottom completely covered with rust, not a sign of paint left. Weather generally good throughout.

Voyage 2.—Bottom cleaned and painted at Cardiff. Dry-docked at Tyne; bottom rather dirty. Weather generally good throughout.

Voyage 3.—Bottom cleaned and painted at Tyne. Weather generally good throughout.

Voyage 4.—Not in dry dock. Weather generally good during outward passage, but very rough during greater part of homeward passage.

(Mr. John R. Fothergill.)

these four voyages, both the two Indian and the two Mediterranean, corresponded with remarkable accuracy with the trial itself, in which the coal consumption per hour per indicated horse-power was 1·46 lbs.

One point to which attention might be drawn was that, with this consumption of 1·46 lbs. of coal per indicated horse-power per hour, as given in the report, the temperature of the feed-water was only 106°, due to its passing through the measuring tanks. The usual temperature of the feed-water was 159°, which implied nearly 5 per cent. less heat for its evaporation. Therefore if 5 per cent. were deducted from the actual coal consumption in the trial, it would be brought down to 1·39 lbs. per indicated horse-power per hour, which corresponded with the 1·38 lbs. obtained by the chief engineer with the feed-water temperature of 157°.

Mr. Thomas Mudd, manager of the Central Marine Engine Works where the "Iona" was engined, considered it a fortunate circumstance that the trial now reported had been made in a steamer whose chief engineer had afterwards made such careful efforts to get independent information for himself, which could be read parallel with Professor Kennedy's trial, thereby affording a valuable corroboration of the results reported. It was also fortunate, he thought, that the ship happened to be one of a fleet superintended by Mr. Fothergill, whom he knew to be one of the most particular, untiring, and methodical of superintending engineers in his endeavours to get at the whole history of the ships under his charge. Although he had not had the advantage of being present at the discussion of the Committee's previous trials, he understood it was their wish that the discussion should deal with the trials themselves and the methods in which they were conducted, rather than with any questions of the construction of the engines. With this wish he would endeavour to fall in as far as possible, although naturally the line of demarcation was rather indistinct; in fact it seemed to him that the construction of the engine was in some measure inseparable from a trial of this kind, because when results were reported any engineer at once weighed them in his own mind, and formed his own

conclusion as to whether they were good, bad, or indifferent. If they were good or bad, he immediately wanted to know why; and the answer to such an enquiry at once opened up the question of the construction of the engine and the machinery generally. Without some knowledge of what had caused the good or bad results to be obtained, the knowledge that they were good or bad was of little use.

At the outset he wished to say that for himself he was highly satisfied with the trial now reported. The greatest possible care and attention had been devoted to it by Professor Kennedy; and the keen interest that his assistants had taken in every detail of their duties was a further guarantee of the accuracy of the result. There were also other reasons for feeling satisfied with the trial. One reason was that the coal consumption came out so closely in accord with the best results which the chief engineers on board this and other ships at sea had been able to get with the same make of engines. Another reason had regard to the water consumption, which he had never before been able to get measured; there had always therefore been some degree of doubt in his mind as to what really was the consumption of water, and it could be arrived at only by ascertaining the efficiency of the boiler and then calculating the water consumption from the coal consumption. It was therefore gratifying to find that the measured water consumption had come out considerably less than he had ventured to hope. The engines and boilers of the "Iona" were of the ordinary type regularly supplied to cargo boats by the works of which he had charge; the only exceptional points about them were that the boilers had tubes a quarter of an inch smaller in diameter than those usually fitted, and were worked under the system of forced draught described in the report. That the results obtained by Professor Kennedy were really economical, he thought it would be generally agreed; and with regard to the question whether the application of the forced draught had anything at all to do with the economy of the results arrived at, he might mention that, having now fitted three steamers for Mr. Fothergill on this system, he was certain the advantages of forced draught had at any rate been secured without any loss of efficiency. This was of course a great point to be satisfied about.

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Turning to the diagram of the back of the engines, Fig. 27, Plate 54, which showed the measuring tanks in position, it would be noticed that one of the principal features of the engines was the arrangement of the cylinders. The high-pressure cylinder was placed in the middle, and it had three walls round it, Fig. 31, Plate 56. The innermost wall was of course the working barrel. The space between the inner and the middle wall formed a steam-jacket at full boiler-pressure; this was the only jacket about the engines, and was the one referred to throughout the report. The space between the middle and the outermost wall was partly the receiver between the first and second cylinders, but mainly the receiver between the second and third. The jacket therefore gave off heat inwards to the first cylinder, and outwards to the two receivers. Doubtless this double action of the jacket accounted for the large jacket-condensation recorded in the report (page 210), namely 4·3 per cent. of the whole feed. When the engines were at work in the ordinary way without measuring tanks, two objects were accomplished at once by simple means: namely a well drained jacket and a highly heated feed were secured by simply carrying a drain pipe from the jacket into the feed suction-pipe, which took the water from the hot-well to the feed pumps. At D was the drain valve from the high-pressure jacket; and when the engines were in their ordinary condition the drain pipe from D was taken down at the back of the engine and turned up at S underneath the suction-pipe to the feed pumps. In that way the feed could be heated up to 160° or 180° Fahr. without the pumps refusing duty. The temperature of 180° was the highest that it had been found practicable to secure without the feed pumps giving rather too much trouble from the vapour formed; but 165° and 170° were common temperatures with this arrangement. There were thus in ordinary working three causes that tended towards economy:—the position of the jacket, especially in relation to the receivers; the efficient drainage of the jacket; and the use of a high feed temperature in conjunction with a low condenser temperature. During the Committee's trial one at least of these causes was necessarily interfered with, namely the feed temperature; because

the act of measuring the feed-water in tanks which took a quarter of an hour to fill (page 207) brought the temperature down to an average of 106° Fahr., as shown in Fig. 1, Plate 44. As it might yet possibly have been doubted whether this difference would be sufficient to produce any effect on the coal consumption, it was fortunate that the chief engineer had been able to make a subsequent trial of the coal consumption on the same method as that adopted by Professor Kennedy, but omitting the water measurements. The subsequent trial showed in a most satisfactory manner that, had the feed temperature in the earlier trial been 160° instead of 106°, the coal consumption would have been somewhere near that arrived at in the subsequent trial, namely 1·38 lbs. per horse-power per hour, instead of the 1·46 lbs. recorded in the earlier trial. The effect of this lower coal consumption upon the percentages of efficiency given in pages 213 and 215 would be to increase the boiler efficiency from 69·2 (page 213) to 73·4 per cent., and to increase the total efficiency from 11·8 (page 215) to 12·5 per cent.; the engine efficiency would be left where it was, namely at 17·1 per cent. (page 215).

The supplementary feed supply on the trial amounted to as much as 6·1 per cent. of the total feed (page 211). It might be explained in passing that the supplementary feed, sometimes called the "feed make-up," was the water that must be added from the sea to make up for all leakages of steam or water either from the boilers or the engines, or from the feed-pumps or pipes connected therewith. It was noticed in page 207 that the feed-pump glands were not quite in order; but the leakage did not appear to be anything alarming, although the fact of turning on suddenly a big tankful of water, causing the pumps to run almost full, had a tendency to make the leakage worse. There was also some leakage at the large 4-inch cock at the bottom of the measuring tanks. Although these leakages were not thought to be serious, yet it was astonishing what a large quantity of water could pass in sixteen hours through what appeared to be only a small leak. Here again a careful test made by the engineer in this very ship, but previously to the Committee's trial, and covering as long a period as nine days, showed what would naturally be expected, namely that 6·1 per cent. was greatly in excess of the supplementary

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supply ordinarily necessary. Fortunately the horse-power during the nine days' test was about the same as on the Committee's trial, certainly not less: so that the same total feed might safely be taken for a basis of comparison. In the diagram, Fig. 24, Plate 52, was shown graphically by the rising line the continuous progress of the supplementary feed in the "Iona" during that extended nine days' test, during which the feed-pump glands were tight; whence it would be seen that the quantity represented less than 1·3 per cent. of the total feed, instead of 6·1 per cent. The diagram, Fig 25, showed the water level in the boiler, as observed at intervals during the whole of the nine days. Now assuming that during all that period there was absolutely no leakage at the feed-pump glands, it would appear that during the sixteen hours' trial as much as 6,622 lbs. of water must have been measured without ever reaching the boilers. It was clear that whatever water was lost either at the 4-inch cock at the bottom of the measuring tanks or at the feed-pump glands was lost after it had been measured, and on its way from the measuring tanks to the boilers, because it passed from the measuring tanks to the feed-pumps, and thence through the feed pipe to the boilers. If then a correction were made for this loss in the feed on its way to the boilers, it would be found that the water consumption would be reduced by $6 \cdot 1 - 1 \cdot 2 = 4 \cdot 9$ per cent., that is, it would be reduced from 13·35 lbs. per indicated horse-power per hour to about 12·69 lbs. The efficiency of the boiler would thereby be reduced from 73·4 to 69·8, which nearly brought it back to the efficiency of 69·2 given in the report. The engine efficiency would be increased 4·9 per cent. from 17·1 to 18 per cent.; and the total efficiency would be left where it was after the last correction, namely 12·5 per cent. It would therefore appear that, taking advantage of one trial to check another, the most accurate statement which could be made of the efficiency of the machinery was that the boilers were delivering about 70 per cent. of the heat of the fuel, and the engines were delivering horse-power equivalent to about 18 per cent. of the heat of the steam generated, that power being equivalent to just about 12½ per cent. of the total heat of the fuel.

Attention had lately been called to the condensation taking place in cylinders, and in page 215 it was stated that at a pressure of 125·4 lbs. per square inch above the atmosphere there was present in the high-pressure cylinder according to the indicator diagrams 63·4 per cent. of the feed as steam and 36·6 per cent. as water; at 19·4 lbs. pressure in the intermediate cylinder there was 74·9 per cent. steam and 25·1 per cent. water; and at 8·6 lbs. pressure below the atmosphere in the low-pressure cylinder there was 59·1 per cent. steam and 40·9 per cent. water: these calculations were made on a total water consumption of 2·35 lbs. per revolution, which agreed with the 13·35 lbs. per indicated horse-power per hour. Here the previous correction of 4·9 per cent. for feed water measured but not put into the boilers would reduce the total water per revolution to 2·23 lbs., and would alter the foregoing percentages of steam and water to the following:—at 125·4 lbs. pressure, 66·5 per cent. steam and 33·5 per cent. water; at 19·4 lbs. pressure, 79 per cent. steam and 21 per cent. water; and at 8·6 lbs. pressure below atmosphere, 62·4 per cent. steam and 37·6 per cent. water. An attempt he thought might be made to apportion the cylinder condensation by the aid of known quantities, and thus to reduce the unknown source of loss to a minimum. In the present instance it was known (page 210) that 6·15 lbs. of water went through the jacket per minute, and that 0·88 lb. per minute was collected from the steam-pipe and high-pressure valve-chest drains, making together 7·03 lbs. per minute, none of which ever went into the cylinders at all. Making therefore a corresponding further reduction under these heads in order to try to arrive at the actual condensation within the cylinders, the total weight of feed-water really entering the cylinders would be reduced to 2·12 lbs. per revolution, and the percentages of steam and water would be altered to the following:—at 125·4 lbs. pressure, 70·5 per cent. steam and 29·5 per cent. water; at 19·4 lbs. pressure, 83·2 per cent. steam and 16·8 per cent. water; and at 8·6 lbs. pressure below atmosphere, 65·7 per cent. steam and 34·3 per cent. water. There was yet another circumstance causing the water in the intermediate and low-pressure cylinders to be less again than the last-named figures: namely that the drain cocks on the two receivers

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were kept continuously open; but as the drainage from them was not measured, a correction could not be made under this head. Neither should it be supposed that the whole or nearly the whole of the water actually existing in the cylinders was to be attributed to the somewhat mysterious cause called initial condensation. Valuable results he thought might be arrived at by attempting to subdivide further and to apportion to known causes as much as possible of the cylinder water. For instance the cushioning steam, although existing as steam in the cylinder, was not measured or taken into account at all, but was properly regarded theoretically as a constant quantity, which was simply expanded and compressed continuously, like stretching and relaxing an elastic band. But the fact had to be borne in mind that work could not be taken out of steam and put back into it again without loss: there must be a loss in the act of expanding, and again a further loss in the act of compressing. If therefore the cushion steam were not replenished to the necessary extent at each revolution, in a few revolutions it would all be gone. The quantity that was lost by condensation had therefore to be made up by fresh steam at every stroke. If the precise deficiency of the cushion steam could be determined, then the water found in the cylinder might be subdivided, and the proper share be apportioned to this inevitable source of loss. On these same grounds he had been hoping much from the ingenious attempt made on the trial to determine the priming water (page 210); and if the condensing apparatus had not broken down, it would doubtless have furnished sufficient data for charging to this cause also its proper share of the water found in the cylinders. In these ways, if followed up more fully, it did seem to him that the bulk of the water might be apportioned to known causes, thus reducing the amount which should properly be regarded as due to initial condensation, and perhaps removing altogether the apparent mystery which still hung over this subject.

In Fig. 26, Plate 53, was shown a theoretical combined indicator diagram compiled from the mean indicator diagrams of the "Iona," Plate 47, with the object of representing in four different ways the ratio which the realised work of these engines bore to the theoretical work of the same steam. All the horizontal net measurements of

the mean indicator diagrams in Plate 47 had here been set off from a vertical line G H, thus obliterating the effect which the compression had upon the appearance of the diagrams. This caused the diagrams from the three cylinders to overlap one another; and the areas of the overlapping portions were therefore compensated by the addition of the two equivalent areas V V. The distance between the two vertical lines A F and G H represented the volume of the compression steam at the moment of the admission to the high-pressure cylinder; and in the present instance this volume was just equal to the clearance volume, because it would be seen from the high-pressure diagrams in Figs. 6 and 9 that the compression curve ran up just to the admission pressure. The upper and lower limits of the theoretical diagram—the line A B at top and the line F E at bottom—were the highest and lowest pressures indicated in the high-pressure and low-pressure cylinders respectively: lower still there was the zero line at 14·58 lbs. per square inch below the atmosphere (page 213). The volume M N at 125·4 lbs. per square inch represented the 1·49 lbs. weight of steam per revolution, which in page 215 was stated to be accounted for by the indicator diagrams as present in the cylinder at that pressure. The point N therefore had been taken as the origin of the two theoretical expansion curves N C D and N J K, which were both of them what were known as "ten-ninth or nine-tenth" curves; that is, the ninth power of the pressure varied inversely as the tenth power of the volume. The outer curve B C D represented the expansion of the whole steam in the cylinder, including the cushion steam A G; and the realised work, represented by the shaded area, amounted to 75 per cent. of the whole theoretical work, the latter being represented by the area A B C D E F comprised within the outside lines of all. If the area A G H F were left out, the work realised would be 83 per cent. of the remaining area G B C D E H; but this percentage was of little value, because, if the cushion steam A G were to be left out of the comparison at all, it ought to be left out not up to the line G H only, but up to an expansion curve drawn down from G for the quantity of steam A G. The more interesting way of looking at the percentage was to take the inner curve B J K, representing the expansion of the working steam M N alone, as

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though it were expanded in one cylinder to a volume H E equal to the volume swept through by the low-pressure piston. Then the realised work amounted to as much as 103·5 per cent. of the smaller area G B N J K E H. Yet again, if from both the theoretical and the actual diagrams were omitted, as it ought to be, the piece above M N, which represented the wire-drawing before the valve finally closed at the cut-off N, the realised work then rose to 105·2 per cent. of the smallest theoretical area M N J K E H. This excess apparently meant that some portion of the water found in the cylinder at the pressure of 125·4 lbs. became subsequently evaporated and performed some work. The question as to how far it was economical or the reverse to allow the engine thus to act as a boiler, turned he thought upon the source whence the water came: that is, whether it came from an unnecessary or from a necessary source. If it came from priming or from excessive initial condensation, it would certainly be undesirable to see the expansion curve bulging out through the evaporation of water which should have been prevented from being present in the cylinder at all. But if it were the inevitable condensation due to the performance of work, or the equally inevitable condensation due to the compression of the cushion steam, then he was of opinion that there was economy in getting what work could be got out of the water which must from these insurmountable causes be present in the cylinder. To the usual suggestion that, if the steam which was put into the jacket had instead been put into the cylinder, more work would have been realised, he thought in the present case there was a good answer. If the jacket steam had been put into the cylinder, it could not have lengthened the line M N in any greater proportion to the whole jacket-water than the proportion which M N itself bore to the whole feed-water; and when that small addition was made to M N, and a new expansion curve drawn down, it was found that the realised work became almost precisely equal to the theoretical area in which the jacket steam was so included. It appeared to him unlikely that this would have been the case, if the jacket had not been in existence.

A high degree of economy in an engine could be attained only by the aid of a great number of details, which all alike tended towards that end, instead of counteracting each other. For instance, the steam must be thoroughly bottled up in the cylinders during the time that it was wanted there, as a very slight leakage past the valves or pistons was disastrous to economy. This consideration had led him now to adopt as a regular principle in marine engines the common slide-valve for each cylinder, in place of the piston-valve, as he had found it not possible to keep the piston-valve quite as steam-tight over long periods as the slide-valve: although he knew of a number of piston-valves working at sea, which did not wear more than the thickness of a piece of writing paper in a year. On the same account he had devoted much attention to the pistons also; and the design he had been using for some time was quite steam-tight he believed, whilst it ran with remarkably little friction in the cylinder. A large vessel was now in London after her first round voyage to New Zealand, and on gauging her high-pressure cylinder and piston packing-rings no measurable wear could be detected in either, when compared with the shop gauges to which they had been made. In another instance after three years' wear the difference between the gauged cylinder from the ship and the standard preserved in the shop could hardly be seen; it was only about the thickness of a piece of writing paper. Another condition of economy was that the steam must be supplied to the engine fairly dry; and if dry steam were supplied, the greatest care was necessary in the construction of the valves and piston packing-rings, otherwise a trouble of a mechanical nature would arise from seizing. It was unnecessary however to enlarge further upon such well-known principles as these in the construction of machinery.

Mr. Francis C. Marshall was much struck by the great size of the boilers used in the "Iona." It appeared to him almost a necessity that highly economical results should be obtained in these trials, seeing that the boilers had a heating surface of nearly 5 square feet per indicated horse-power. The owners of the vessel he thought might be thankful that in these matters they had the guidance of so

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experienced an engineer as Mr. Fothergill; for he did not know of any other owners who would tolerate ships of that size and engines of that size running at 8·4 knots per hour and developing only 645 horse-power with boilers having as much as 3,160 square feet of heating surface. In his own experience he had found that nearly double that power was demanded by the owners from such an extent of heating surface; and the engineer was a proud man who was allowed to put such large boilers into ships, where so little power was to be got out of them.

The temperature of the funnel gases, he was interested in finding, had come much to the front in the series of trials conducted by Professor Kennedy; and the results of the observations made were remarkable. With the first-rate boilers of the "Iona," the average temperature of the funnel gases (page 206) was found to be only 452° Fahr. In the reports of the previous trials (Proceedings 1889 page 241, and 1890 pages 207 and 218 and 230) he found that the temperature of the funnel gases in the "Meteor" was 791°, in the "Fusi-Yama" 578°, and in the "Colchester" 835°; whereas in the "Tartar"—engined also by a Hartlepool firm, and having the heating surface in the same extravagant proportion as the "Iona" of nearly 5 square feet per horse-power—the temperature had again come down to 477°. These were important facts and well worth noting. In Table 10 he observed that the mean temperature of the chimney gases in the chief engineer's trial of the "Iona" was given at 672°, as indicated by a pyrometer in the uptake of the furnace, by which would ordinarily be understood the large flame-box or combustion chamber at the back of the furnace; and he enquired whether it was not in the smoke-box, instead of in the flame-box, that the temperature of 672° had been measured.

Mr. John R. Fothergill replied that the pyrometer measurement had been taken in the uptake to the chimney, that is in the smoke-box in front of the tubes. Therefore 672° was the temperature of the gases after leaving the boiler.

Mr. Marshall called attention also to the ratio of the total heating surface to the grate area, which in the "Iona" was 75 to 1;

whereas in all the previous trials the ratio was much lower (Proceedings 1890, page 237). In the "Meteor" it was 32 to 1, in the "Fusi-Yama" 43 to 1, in the "Colchester" 27 to 1, and in the "Tartar" 33 to 1. This comparison was well worth considering, and was itself quite enough to justify the trials; and it showed the great advantage that was being derived from the application of forced draught. If out of a grate area so small as only 1–75th of the heating surface such results could be got in the "Iona," he thought that in all steamers it was desirable to employ forced draught. With so manageable a length of grate as only 3 feet or $3\frac{1}{2}$ feet, and with such an efficiency as was shown in the present case, it seemed to him there could be no question as to the desirability of fitting every steamer with a fan and using forced draught. The combustion was then much better, while at the same time the temperature of the escaping gases was much reduced in consequence of having such a large proportion of heating surface to grate area. In calling attention to these special features of the "Iona" and of the trials, he submitted that to a large extent the highly satisfactory results which had been realised had been obtained by virtue of the large boilers and of the small power developed out of them. In conclusion he wished to express the great indebtedness of the engineering profession to this Institution and to Professor Kennedy for the results which had thus been placed at their disposal. Nothing could be more valuable than the trials which had already been conducted, affording as they did data from which engineers would be able to produce more and more satisfactory results in the future.

Mr. J. Fiddes Brown, in explanation of his reason for making the subsequent trial, so closely preceded as it was by such an elaborate and careful trial as that carried out by Professor Kennedy, said that, when the results were roughly estimated at the end of the Committee's trial, they did not appear to him quite so good as he had anticipated, in comparison with the average coal consumption during the two previous voyages, which had together amounted to about 150 steaming days. Not that the consumption was more in

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the trial than in the voyages; but he had expected it to be less, because during a voyage the average coal consumption per day included certain losses at foreign coaling stations, due to inferior quality of coal and short weight, which together might safely be estimated at 10 per cent. of the nominal weight received abroad. The coal received abroad was usually about half of the total quantity required for the voyage. Moreover the average daily consumption included also any loss due to the main boilers supplying steam to the steering engine &c. under ordinary conditions of running. He had therefore fully expected that the consumption would work out less in a trial in which all the coal was carefully weighed. As however one or two of the conditions under which the Committee's trial was made had appeared to him somewhat to vitiate the result, he had thought that a subsequent trial made under normal conditions of running would give a rather better result.

The feed-water temperature during the Committee's trial was about 50° below the usual temperature, which seemed to show that there was a considerable loss of heat in consequence of the feed-water passing into the measuring tanks and being retained in them for a certain length of time, instead of passing direct from the hot well to the boilers.

The supplementary feed-water in the Committee's trial, amounting to 6·1 per cent. of the total feed-water, was excessive. It was not an excess of only 5 or 10 per cent., which might be neglected; but it amounted to about five times the usual quantity. The whole of it was no doubt supplied and measured in the tanks, but 80 per cent. of it never got further than the feed-pumps, owing to the excessive leakage of the glands. The supplementary feed diagram, Fig. 24, Plate 52, presented a graphic record during a period of nine days in a voyage previous to the trial; and the mean of the whole diagram was equal to 1·28 per cent. of the total feed. Moreover during a period of 23 hours 20 minutes included in this diagram, namely from 4.40 p.m. on the first day to 4.0 p.m. on the second, only 185 lbs. extra water was supplied, and the boiler level fell 1⅞ inch, which was equivalent to 2,397 lbs. of water or 1·19 per cent. of the total feed-water; this was within 0·1 per cent. of the mean of the whole

diagram, and thus appeared to be a good check on the whole record. The excessive waste of supplementary feed-water in the Committee's trial considerably affected the reported consumption of feed-water per indicated horse-power per hour, as already pointed out by Mr. Mudd (page 232).

In order to estimate correctly the quantity of heat carried away by the funnel gases, it appeared to him that their temperature ought to be observed as soon as possible after they had left the tubes, as had been done in the subsequent trial, instead of half way up the funnel as in the original trial. From a series of simultaneous observations with a pyrometer in each position, he had found that the temperature was 105° higher in the lower position, which was $23\frac{1}{2}$ feet below the upper; the pyrometers used were the same as in the original trial, in which therefore the temperature in the lower position would seem to have been 557°. This would leave 115° excess in the subsequent trial still to be accounted for, which was probably due to a smaller weight of air per lb. of coal in the latter trial. The actual weight of air in this trial he was unable to estimate directly, not having had any means of taking samples of the furnace gases; but an approximation he thought could be arrived at in regard to it, by estimating the velocity at which the air passed through the gridiron valve into the ashpit and also through the back air-valve into the combustion chamber. The mean differences of pressure between the outside and the inside of the air openings in the Committee's trial were 0·55 inch of water at the ashpit valve and 0·34 inch at the combustion-chamber valve, and in the subsequent trial 0·45 inch and 0·78 inch respectively. The temperatures of the air in the first trial were 123° F. on entering the ashpit, and 80° F. on entering the combustion chamber; and in the second trial 134° and 90° respectively. As the weight of air used in the first trial was known exactly from the analyses of the chimney gases, namely 24·5 lbs. per pound of coal (page 214), the coefficient of influx into the ashpit and combustion chamber could be found; and applying this to the weight of air arrived at by calculation in the second trial, it was found that about 23·1 lbs. of air must have been used per pound of coal in the latter case. During the first

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trial about 7½ per cent. of the whole air passed direct to the combustion chambers, and during the second trial about 11·4 per cent.

The indicators in the subsequent trial having been attached to the cylinders by the usual long pipes and bends (page 216), he thought the mean indicated horse-power deduced from the diagrams so taken might safely be considered to be below the true power; for before the Committee's trial was commenced, and with the indicators attached as in that trial in as direct a manner as possible, a set of diagrams had been taken at 64 revolutions per minute and with 155 lbs. boiler-pressure, which represented a total of 733 indicated horse-power. If the power to drive a ship were considered to vary approximately as the cube of the speed, a comparison of the ship's speeds per hour or of the revolutions per minute in the two trials would give as the indicated horse-power in the subsequent trial 739 or 738 respectively, which was an increase of about 4 per cent. upon the mean of 707·7 indicated horse-power in the latter trial. Considering therefore the power to have been 733 I.H.P., the coal consumption in the subsequent trial would be 1·33 lbs. per indicated horse-power per hour, instead of 1·38 lbs.; and taking 12·69 lbs. of water per indicated horse-power per hour, as calculated by Mr. Mudd (page 232), the evaporation per pound of coal would be 9·5 lbs. of water from the temperature of the feed.

Mr. P. W. WILLANS considered the Committee were to be congratulated on having had in the "Iona" such excellent engines to experiment upon as these designed by Mr. Mudd, which appeared to him to be a long way ahead of any others, and all the more interesting on that account. With regard to the causes that had led to the good results reported, compression had been mentioned by Mr. Mudd (page 234) as causing condensation. It appeared to him however that in this engine the compression had not caused condensation, but had to a great extent prevented it. The effect of compressing the steam to the extent shown in the high-pressure diagram, Figs. 6 and 9, Plates 46 and 47, was that before the admission of the boiler steam the temperature of the cylinder walls was raised, as was also the

temperature of the water that was already present in the cylinder. In spite of the compression however it appeared from the report that only 63·4 per cent., or according to Mr. Mudd's calculation (page 233) only about 70 per cent., of the total feed-water was found in the shape of steam at the cut-off in the high-pressure cylinder. Even the 30 per cent. difference did seem a great deal to lose. In higher-speed though smaller engines he was accustomed to get this loss down to about 5 per cent. with late cut-off in the high-pressure cylinder of a triple engine, and possibly to about 15 per cent. with the most economical ratio of expansion in the high-pressure cylinder of a triple condensing engine; and he thought a way would eventually be found of reducing it to this extent in all engines. The jacketing of the high-pressure cylinder had been mentioned by Mr. Mudd (page 230) as likely to have added a great deal to the good result. It appeared to him however that 4·3 per cent. of jacket water was a smaller quantity than might have been expected, considering that the jacket was applied both to the cylinder and to the receiver; it was less than was usually met with in cases where economy resulted from the use of the jacket; and he enquired whether it had been possible to make any trial of these engines without the jacket. No good result in his opinion could possibly be produced by using high-pressure steam in the jacket for re-boiling in the cylinder the water corresponding with the work done in it. The only good effect that the jacket could have was by preventing the presence of water on the cylinder walls. In regard to the general results of the trial, one of the principal points was the large boiler power. The great thing was to work a boiler moderately, and an engine as hard as it could be driven.

Mr. H. R. J. Burstall, having had the pleasure of being one of the observers in the trial, wished to dispel any impression of there having been a great leak at the feed-pump glands or elsewhere. The watch at the water had been taken by himself and Mr. Legros, and they would have observed any leak at the feed-pumps or at the big cock at the bottom of the measuring tanks. Instead of a loss of more than 6,000 lbs. as estimated by Mr. Mudd (page 232), he imagined the

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quantity of water lost from that cock might perhaps be about 200 lbs. at the outside. The feed-pump glands leaked during about the first hour and a half, but comparatively little afterwards throughout the rest of the trial.

Mr. Thomas Mudd drew attention to the circumstance that, while it was acknowledged that there had been a considerable leak at the feed-pump glands during the first hour and a half of the trial, the continuous line of the supplementary feed, plotted in the diagram, Fig. 22, Plate 51, was nearly regular all through the time, indicating a continuance of leakage to nearly the same extent throughout the remainder of the trial.

Mr. Stephen H. Terry, being connected with the inventor and maker of the engine and fan used for the forced draught in the "Iona," noticed that the fan had been running at the mean speed of 180 revolutions per minute during the trial (page 203), and had apparently been delivering 24·5 lbs. of air per lb. of coal (page 214). The coal consumption was given as 15·7 lbs. per minute (page 206), to which would correspond a delivery of 384·6 lbs. of air per minute; and allowing roughly 13 cubic feet per pound, the actual volume of air delivered during the trial would appear to have been about 5,000 cubic feet per minute, showing a large reserve of capacity in the fan, which was constructed to deliver 14,000 cubic feet per minute at 400 revolutions per minute, and had done so when tested at the works. The remarkable evaporative result attained, namely 9·15 lbs. of feed-water per lb. of coal, equal to 10·63 lbs. at 212° Fahr., was doubtless due partly to the good design of the boilers, and partly to the method of combustion provided, by which, although only a comparatively small volume of air was supplied to the fires, yet that volume arrived under such conditions that carbonic acid gas alone was formed, not carbonic oxide; and as the total volume of inert nitrogen passing through the tubes was also comparatively small, fewer units of heat than usual were wasted up the chimney, the loss from this cause being only 16·2 per cent. of the calorific value of the fuel. This condition of things, giving the gases time to impart heat to

the tubes, which had been termed a soaking heat, had been brought about by the mechanical appliances employed by Mr. Fothergill.

In the boilers he observed that corrugated flues were used; and he wished to know whether any means had been taken to prevent the leakage of air past the fire-bars in the immediate vicinity of the corrugations, because that was an important point with which the future success of forced draught, at any rate at high pressure, was closely connected. Some trouble had been experienced with corrugated furnaces from that cause where a high air-pressure had been used, which he thought might readily be prevented, and should not be allowed to stand in the way of future progress of forced draught, as he believed that corrugated furnaces and forced draught could be made to go well together. It was also mentioned (page 203) that during the trial the fan engine took steam from the donkey boiler; and he should like to know what the pressure of the steam was, and whether the throttle-valve of the fan engine was fully opened, or how far open. The power required for the small air-pressure used was low, amounting to only 2·1 indicated horse-power, and it appeared to him that the valve must have been nearly closed. As he believed Mr. Fothergill had had large experience of these high-speed engines, he should be glad to know how he had found them answer on the whole; and whether the closed-in construction of engine, which was sometimes objected to, had given any trouble.

In the air trunk near the fan he observed that the air pressure in the trial (page 203) had been 0·86 inch of water, and at the back of the boilers 0·34 inch, whilst in the ashpits it had fallen to 0·17 inch, or a fall of more than half and four-fifths respectively. Yet from Plate 57 it would be seen that the airways were comparatively large, and that the air had only two bends to turn. Doubtless the pressures would have been better maintained with larger airways, although the present airways gave all that was wanted by the fires. There were many points in connection with the flow of air driven by fans through air trunks, which were well worth careful study; and it could scarcely be doubted that numbers of installations of forced draught, where much larger volumes per square foot of fire-grate and higher air-pressures were used than those described in

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the report, were seriously crippled by narrow and tortuous airways with sharp bends. These resulted in reduced delivery of air, or, if the delivery must be maintained, the fan engine had to run perhaps another hundred revolutions per minute. If the bends in the air trunks were made with some approach to the same easy curves that were used for the ship's sides, quicker flow of air would be obtained with less expenditure of power, just as in the ship higher speed was realised. A fan in dealing with air was like a centrifugal pump in dealing with water: it was a highly efficient machine for a large volume at a low head. But if the delivery were checked by numerous bends, although the pump would continue to absorb the same power as before, it would almost cease to deliver any water; and in this way a fan, although running beyond its intended speed and with high water-gauge in the fan casing, might deliver to the fires a small volume of air and at low pressure, owing to the loss of head by sharp turns and surface friction, setting up eddies, whereby the velocity given to the air by the fan was expended in producing internal movements, instead of in moving forward. Recently some experiments had been made by Mr. Robert S. Williamson of Hednesford, with a Chandler colliery fan drawing 50,000 cubic feet per minute, and ventilating one of the Cannock pits having a large shaft some 400 yards deep. The driftway opening from the upcast shaft, leading to both sides of the fan and under the fan, was 4 feet by 6 feet, having therefore an area of 24 square feet and an air velocity of about 35 feet per second. The vacuum in the pit shaft below the mouth of the drift was 0·6 inch of water, whilst that in the drift near the fan was 1·1 inch, thus showing that half an inch of water pressure, or nearly half of the whole load, was wasted by the drift. By enlarging the drift, as had now been done, to double its previous size, the velocity had been halved, and the delivery of air greatly augmented without perceptible increase in power expended; and the vacuum in the drift and in the pit had been brought nearer together by 0·2 inch. Just as mechanical ventilation was displacing the older ventilation of collieries by a furnace at the bottom of the shaft, so he believed would draught induced by fans displace tall chimneys and wind-sails, which, however efficient in cold weather

and with a good head wind, were not to be relied on in hot climates and with a following wind. It was of the greatest importance in a steamship to have complete control over the air supply to the fires.

Mr. Druitt Halpin thought the Institution was to be congratulated on the present report, giving as it did such a number of valuable facts, put so clearly and concisely; and also the designer of the engines, on the great success he had achieved in making such economical engines of this type. The Committee had here carried out a splendid trial; but if there was a desire to popularise such trials, he was still of the opinion which he had previously expressed, that it was not the easiest way of doing so to continue the use of the present measuring tanks, getting them fitted into the ships for the purpose of obtaining the water measurement which was absolutely essential. In the present trial the quantity of water dealt with by the measuring tanks was 8,616 lbs. an hour; and the only hitch that had thus far been mentioned had been what seemed to him to be a vital discrepancy among those who were present at the trial, as to what had happened in regard to the leakage of the feed-pumps and of the tank cock. On a former occasion he had recommended the use of meters for the water, and he was still decidedly in favour of that mode of measurement. Since then there had been still further experience in this matter, and in many large central electric-lighting stations, where it was necessary to take accurate observations, he understood that water meters were being used with great success, giving really correct results on boilers which were taking considerably more water than was used in the present trial. The whole meter was under 2 feet diameter, and worked just as the engine counter worked, from one end of the year to the other; and the quantity of water was noted every day, just like the coal consumption. In trials on board ship a meter could be used with a simple by-pass, if desired; and this arrangement appeared to him preferable to employing tanks, which involved the difficulty of finding space for them, and the expense of fitting them in one ship after another.

One point, on which he thought it would be of great value if the Committee could see their way to give information in any future trial,

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was the quantity of the circulating water. It was true that the temperature and weight of the exhaust steam were already known, and also the temperatures of the entering water and of the discharge water: so that from the rise of temperature the quantity of the water could be calculated. Nevertheless if it was in any way possible he should much like to have a check upon the calculation by actual measurement of the volume. There would then be the means of seeing whether it was commercially more economical to drive a larger body of water through a smaller condenser or a smaller body of water through a larger condenser.

In the description of the "Iona" engine it had been stated that the high-pressure cylinder was in the middle, and that its jacket drained into the hot well, which he thought was not at all a good plan. How any better thermo-dynamic result could thereby be obtained he failed to see. There might indeed be a better result from a hotter feed, in consequence of better circulation in the boiler, or of freedom from injury to the boiler, or of absence of leakage; but he did not see that any good could come of putting live steam into the feed-water, and in this particular case he thought there was not any excuse for so doing, because the conditions were the most favourable of all for natural drainage. For in these cargo boats and in most sea-going steamers there was a natural fall of about 8 feet between the bottom of the cylinder and the water surface in the boiler, which was quite enough to ensure thoroughly efficient drainage, if a big enough pipe were put on, say $2\frac{1}{2}$ inches internal diameter, with cocks to provide against a break-down.

The jacketing appeared to have been done in a good, efficient, and successful manner, so far as it went; but he thought there was not enough of it. If the intermediate cylinder and especially the low-pressure cylinder had also been jacketed, still better results he thought would have been obtained. In a small engine that he knew of, with only 60 lbs. steam and only two cylinders, both of which were jacketed completely, the consumption of feed-water was down to 17·4 lbs. per indicated horse-power per hour, which he attributed solely to the large amount of jacketed surface. In that case the condensation in the jackets amounted to as much as

17½ per cent. of the total feed, instead of only the 4·3 per cent. in the single jacket of the "Iona."

The clearance volumes of the three cylinders (page 202) appeared to him to be abnormally large; and he should be glad to know why they had been made so large. From what had been said by Mr. Mudd (page 237) about the remarkably good results obtained with his pistons, he thought it would be of great value if a drawing could be added of the piston, in order that the reason might be better understood of its freedom from friction, and consequently from wear. With regard to flat slide-valves, he was glad to hear that with a boiler pressure of 160 lbs. these had been found to work efficiently and to keep steam-tight. A great deal of leakage he thought occurred with piston-valves, which were troublesome to keep in working order. Such a first-class example of flat slide-valves working under the most unfavourable conditions, without balancing, and with the whole of the load thrown direct on the eccentric, was a great point in favour of flat valves, and he hoped that an effort would be made to use them.

The boilers of the "Iona" he considered were far too large for the work they had to do. In the trial it appeared they had been evaporating only 2·73 lbs. of water per square foot of heating surface per hour. To such a low rate of evaporation he thought the only parallel that had been accurately recorded was to be met with in what were known as racing portable engines, in which it was found that the best result was obtained when the evaporation was brought down to about 2½ lbs.; if it were lower there was a loss, and if it were higher there was also a loss; but what might be the commercial value of that low rate of evaporation in racing portable engines he was not aware. The serious inefficiency of the "Iona" boilers would become apparent if a boiler were looked upon as a machine-tool, taking into consideration not only its economy in steam production but also its rate of steam production. If these two figures were multiplied together, their product in his opinion formed at least a fair factor of value for representing what the boiler was doing. Taking the amount of evaporation from and at 212° F. as reported from the trial, namely 10·63 lbs. of water per pound of coal, and the rate at

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which it was evaporated, namely 2·73 lbs. per square foot of heating surface per hour, the product of these figures was 29, which was an exceedingly low factor for the value of the boilers. At the other end of the scale was what he believed to be the most efficient boiler in the world, namely the locomotive boiler worked under its ordinary circumstances. Data given some years ago by Mr. Webb showed an evaporation from and at 212° of 10·28 lbs. of water per pound of coal, which was evaporated at the rate of 9·83 lbs. per square foot of heating surface per hour (Proceedings 1884, pages 109–111). These figures multiplied together gave 101 as the factor of value for the locomotive boiler, in comparison with 29 for the boilers in the "Iona." Apart altogether from the use of forced draught, the circumstances were of course entirely different. The high efficiency of the locomotive boiler he believed was due to the conditions of its working, whereby on the one hand each bubble of steam as it formed was immediately shaken off from the heating surface, which therefore had always solid water in contact with it; and on the other hand, owing to the jarring of the whole machine, every particle of coal in the fire got its proper particle of oxygen, and the fire got shaken up in a way that no other fires did. This effect he had tried for a year to produce artificially in various kinds of boilers by bumping and shaking them in every possible way that he could imagine, but without success.

The furnaces in the "Iona" boilers he considered were splendid, irrespective of the corrugated flues, which were very good. The remarkably small grates, originally only 3 feet 9 inches long and now shortened to 3 feet, appeared to him to be a move in the right direction, giving the stokers complete control over the firing, and leaving no excuse for bad firing or for the grates getting bare at the further end. The chimney of 6¼ feet diameter or 30·7 square feet area was almost as much as three-quarters of the area of the grate, which was a larger proportion than he had ever met with. At the same time, owing to the small amount of coal that was being burnt, it was stated (page 207) that throughout the whole of the trial the damper was kept only one-sixth open. How far it was profitable to make a chimney six times too big he did not know: though of course the fact must

be recognised that the trial was made with good clean English coal, and with everything in first-rate condition, and that some allowance must be made for inferior coal being received abroad, and for bad firing; nevertheless the ratio of six to one gave an unusually large margin. The exact proportion of the funnel area was 73 per cent. of the grate area, or about 105 square inches of funnel per square foot of grate; many engineers were glad if they could get room to put in a chimney of only about 20 or 25 square inches area per square foot of grate, with practically the same height of 50 feet.

With regard to the use of the forced draught, he altogether failed to see its advantage, so far as the Committee's trial went, because the quantity of coal burnt was so small, amounting to only 22·4 lbs. per square foot of grate area per hour, and the whole apparatus seemed so inefficient: even when the fan was generating a pressure of 1·03 inch of water, only 0·32 inch pressure was obtained in the ashpit, being less than one-third. Whether it was worth while, in view of getting so little, to go to so much complication, might be questioned. The fan and engine were of a simple description, and might perhaps be of advantage under heavier loads, when the main engines were working at 700 or 800 horse-power and with much dirtier coal; but in the trial he thought the result might perhaps have been even better if the forced draught had been stopped altogether.

With a boiler pressure of 165 lbs. per square inch above the atmosphere, he should be glad to know how it was that no more than 142½ lbs. initial pressure was obtained in the cylinder during the trial; and whether it was thought there was any compensating gain to set off against the drop of 22½ lbs.

With regard to the average rate of transmission of heat through the metal of the boiler, which was given in page 214 as 3,059 thermal units per square foot of heating surface per hour, he suggested that in future this might be expressed in a clearer way by giving the transmission per square foot per degree of difference of temperature between the hot gases in the furnace and the water in the boiler, because the rate of transmission depended absolutely on that difference of

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temperature. The only assumption to be made was 2,500° F. for the temperature of the furnace, which he supposed would not be objected to; on this assumption the mean between the furnace temperature and the temperature 452° of the chimney gases would be 1,476°, which was 1,103° in excess of the temperature 373° of the boiler steam; so that the rate of transmission per square foot per degree of difference of temperature would be about $3{,}059 \div 1{,}103 = 2{\cdot}77$ thermal units per hour. For locomotive boilers, as he had previously mentioned (Proceedings 1889, page 299), the rate of transmission expressed in these terms had been given by Mr. J. A. Longridge as 11 thermal units: which again bore out his own view as to the comparative inefficiency of these large marine boilers when worked at so low a power as they were in the "Iona."

Although the two sets of results, from the Committee's trial and the subsequent trial made by the chief engineer, were said (page 217) to agree remarkably well, he feared that, notwithstanding all the pains taken, the agreement was only a coincidence. For it had been stated by Mr. Brown (page 242) that his own trial had been carried out with only two indicators, and that these had been connected to the cylinders by long pipes. From his own experience of long pipes for indicators, he now placed no reliance whatever upon diagrams so taken. On a former occasion (Proceedings 1886, page 364) he had given an instance in which the mean pressure shown by diagrams taken with long pipes was increased as much as 38 per cent. when the indicators were afterwards fixed right on the cylinder without any intervening length of pipes. It therefore seemed to him that the whole of the results deduced from the chief engineer's otherwise most valuable trial must unfortunately be vitiated for that reason.

Mr. WILLIAM SCHÖNHEYDER wished to congratulate the Committee on having had such fine engines to test in the present trial. They appeared to be first-class work, and to be giving highly economical results, although there might be some additions made to them with great advantage, as had been pointed out by Mr. Halpin (pages 251 and 218), in the way of avoiding so much loss of initial pressure in

the first cylinder, and in having all the cylinders efficiently steam-jacketed. From the dimensions given in the report it appeared that the volume of the air-pump was only about one-seventeenth of the volume of the low-pressure cylinder; and as there was a surface condenser, a small air-pump naturally sufficed. But from the indicator diagram in Fig. 13, Plate 48, taken from the air-pump, it appeared plain that, under the conditions under which the engines were working, the air-pump might really have been made only about half its present size, and that it would still have given equally good results. In the design of the engines and boilers he entirely approved the bold stroke of making such large boilers for the engines. Hitherto it had been a common fault in marine engineering to proportion the boilers far too scantily for the work to be done; and therefore the evaporation had been poor. In the present case the evaporation was high, although the total work done by the boilers might not be so considered in proportion to their size. The big combustion chamber at the back of the furnace he thought was an admirable arrangement, as was also the use of a grate which was not too long to be properly managed. In connection with the arrangement adopted for getting rid of the water condensation in the steam-jacket, he enquired how the air also was got rid of, which naturally resulted from the condensation of the steam. In the employment of the measuring tanks for the present and previous trials, it seemed to him that the use of the long glass tube running up the side of each tank, to serve as a water gauge for the whole height of the tank, must have necessitated great caution, because if either tube were to be broken the corresponding tank would be rendered inoperative until another glass could be put in, and it might be inconvenient to use only one tank. That seemed to him a weak point in the arrangement for measuring the feed-water.

Mr. John Phillips, referring to the indicator diagrams shown in Plate 48 from the first and second receivers, asked which line corresponded with the upstroke and which with the downstroke of the piston-rod from which the motion was taken. If possible on any future occasion he thought it would be desirable to take a diagram

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also from the under side of the air-pump bucket as well as from the upper side. The diagram from the under side he thought would not be a straight line; and he hardly saw how the power necessary to work the pump could be calculated without ascertaining what was going on below the bucket. The Institution he thought was to be congratulated on the valuable experiment that had now been described, which furnished so many facts for confirming or refuting opinions previously entertained. In the present trial the machinery of the vessel as a whole struck him as being much too big for the power at which it was worked. The engines and boilers he considered were equal to at least 1,000 horse-power; and if that were the case with the boilers, he wanted to know what advantage was gained from having the forced draught. In order to use the forced draught he observed that the fire-grate area was much reduced below what it would be under conditions of natural draught. A fan he admitted was an excellent thing under certain conditions, as in the case of tropical climates, when the air draught was bad; but he would suggest whether, if the grates were extended to more nearly the usual length, the same result might not be got and there might not be certain gains. Perhaps seven feet length might be too much, but possibly five feet might hit the mark, and then the grates would not be difficult to stoke.

For taking the temperature of the chimney he noticed that the thermometer had been placed about 30 feet above the fire-bars; and there was a damper at 17 ft. 8 ins. above the fire-bars, which was only one-sixth open. By that means it seemed to him that the temperature of the gases escaping from the boiler tubes must have been considerably lowered before they reached the thermometer. The funnel itself was unusually large, about five-sevenths of the fire-grate. The subsequent observation taken by the chief engineer at 6½ feet above the fire-bars would be about at the level of the top of the tubes; and that he should consider would be the proper place for taking the temperature of the escaping gases; at any rate the temperatures in the Committee's trial should have been taken below the damper, instead of above it. The measurement also of the chimney draught by the vacuum gauge (page 207), it seemed to

him, should have been taken at a much lower point, as low down in the smoke-box as possible, instead of 30 feet above the fire-grate. How far the chemical composition of the gases, if drawn off from the funnel below the damper, would have been affected by the difference of temperature he did not know; but all these funnel observations he thought should have been taken certainly below the damper.

The position of the link motion was not mentioned in the report, and from the indicator diagrams it appeared to him that it must have been much linked up. He asked whether the plan of maintaining the boiler pressure at 165 lbs., with an initial pressure of only 142½ lbs. in the high-pressure cylinder, had been arrived at by any previous experience; whether it had been found that it was better than lowering the boiler pressure, or whether a lower boiler pressure and a rather later cut-off would not be preferable. From the diagrams in Plate 45 of the indicated horse-power and the boiler pressure it appeared that where the boiler pressure was the highest the indicated horse-power was not so. Thus at 7 o'clock p.m. the boiler pressure was 169 lbs., and the power was only 629 I.H.P.; at 8 o'clock the pressure was 162 lbs., and the power had risen to 645 I.H.P.; at 2 o'clock a.m. the pressure had risen to 170 lbs., and the power had dropped to 642 I.H.P.; at 4 o'clock the figures were 165 lbs. and 640 I.H.P.; and at 6 o'clock they were 170 lbs. and 660 I.H.P. This great discrepancy led him to question whether the higher pressure of steam in the boiler actually produced a better result in the engine. The steam he thought must be much wire-drawn. Between the boiler and the slide-valve chest there would no doubt be other regulating valves besides the boiler stop-valves; and he should like to know whether they were all fully opened, or how much they were opened. It was much to be regretted that the arrangement made for testing the priming had broken down, because if such boilers as these primed, notwithstanding they were so lightly driven, it would seem that there could hardly be any boilers in existence which did not prime. The water line was not given in the report; but by way of a rough approximation he had multiplied the diameter of the boiler by its length, and then divided the indicated horse-power by the product, in order to form some idea of the relative water surface in

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this and the previous trials. In the "Meteor," according to this mode of calculating, the indicated horse-power per square foot of boiler water surface amounted to 4·61, in the "Colchester" to 4·17, in the "Tartar" to 2·83, in the "Fusi Yama" to 2·54, and in the "Iona" to only 2·43. Although this comparison was only approximate, it would probably not be misleading, because all the boilers were within a little of the same diameter. It therefore seemed difficult to understand how boilers with such a large water surface and worked under such easy conditions as in the "Iona" could possibly prime, considering that in the "Meteor" there was no mention of priming, although her boilers were doing nearly double what those in the "Iona" were doing. That there had been no evil effects from priming in the "Meteor" seemed to him remarkable, because a great many boilers had come under his notice where the priming had been excessive; but he never had to deal with boilers so large for their power as these in the "Iona."

In the coal measurement (page 204) he thought the difference between the 6·79 tons weighed into the bunker and the 6·67 tons weighed out for the trial was certainly no greater than might be expected from merely turning the coal over. He had never found that the quantity of coal put into a bunker could be accounted for without allowing a percentage of loss varying with the quality of the coal. Small fine coal naturally required a much larger percentage to be deducted than lump coal. In Table 12 given by Mr. Fothergill (page 227) a deduction of 10 per cent. had been allowed on the quantity of coal received abroad, which he thought was not more than was always lost in putting the coal into the bunkers, drawing it out again, and throwing it upon the fires; but as the shipowners paid for the gross amount, this quantity should be the basis of calculation for comparison with other cases.

The fan engine he thought, although small, should certainly have taken steam either from the first receiver, as intended (page 203), or else from the main boilers direct; because under the circumstances under which it was worked the fan formed one of the adjuncts towards getting the result that was obtained in economy of coal. If any part of the machinery were cut off from the

main boilers and were worked by some other means, that hardly seemed the proper way of testing the performance of the engines and the main boilers.

The supplementary feed, which was given as 8·7 lbs. per minute (page 211), seemed excessive, amounting actually to 19·41 lbs. per indicated horse-power per day. For 1,000 horse-power the amount would therefore be 8·66 tons, instead of the usual estimate of only one ton for that power. The excess was so great that he thought the matter ought to be looked into. No mention being made in the report of the source from which the supplementary feed was obtained, or of any distiller for this purpose, he asked whether it was supplied from the donkey-boiler steam: in which case it would seem that at least a portion of the coal used for that boiler should be charged to the main engines. The quantity of supplementary feed being so abnormally large, whilst the quantity of the total feed was small per indicated horse-power, the question arose, where did the supplementary feed go to, if it was measured but did not reach the boilers. It was stated that practically the whole of the water from the jacket and cylinder drains was returned into the feed-measuring tanks, and therefore re-pumped into the boilers. How was the supplementary feed put into the boilers? In the event of this extra supply coming from water evaporated in the donkey boiler, the coal required to evaporate it was certainly a quantity which under other conditions, such as with the use of an evaporator, would have been consumed under the main boilers. The propelling machinery could not be considered complete without all the auxiliaries necessary to work it when the vessel was under weigh. In the reports of the previous trials he had found no mention of supplementary feed; and for comparing under similar conditions in this respect the present trial with the previous, it seemed necessary therefore to know both the quantity and the source of the supply, as well as the mode of measurement.

Mr. Robert Bruce considered that the value of the present and the previous reports consisted largely in their furnishing a basis of comparison for the performances of various ships. In reading the

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present report the first thing that had struck him was the remarkably good quality of the coal used in the trial, as evidenced by the analysis (page 205), in which it would be observed that there was under 3 per cent. of ash. That fact went a long way to account for the economy of the performance, because the fires did not require to be so frequently disturbed by cleaning as would be necessary with coal having a greater mixture of dirt. Then the analysis of the ashes themselves showed that 56 per cent. of their weight was carbon and combustible. In the "Meteor" trial the ash was 3·46 per cent. of the coal as used, in the "Tartar" 3·42, in the "Colchester" 4·08, and in the "Fusi Yama" 5·11 per cent.; so that the "Iona" had in this respect a great advantage over the previous trials.

By means of the system of forced draught with which he was connected, he considered that boilers of equal size to those in the "Iona" would give with ease 800 horse-power each. The forced draught in the "Iona" he thought was probably meant to be understood rather as assisted draught; because for forced draught he did not see why there should be a funnel with a damper only one-sixth open. The funnels of which he had experience in connection with forced draught had no damper at all; and it seemed to him that, if in the "Iona" trial the fan had been taken away altogether and the damper opened wider, with perhaps a little longer grate, the results might have been, not indeed better, but equally good. The economy due to forced draught consisted essentially in the increased efficiency of the heating surface, the heating of the air supply by the waste gases, reduction in number or size of boilers, and saving of fuel for a given power. As none of these features were discernible in the present report, he could not consider that forced draught, in the sense in which he understood it and was accustomed to deal with it, had been applied to the boilers of the "Iona." From a purely practical point of view, these results did not afford much encouragement to shipowners, if they had to load their vessels with boilers of 123 tons weight (page 204) in order to get 645 indicated horse-power. The value of the larger space occupied by such boilers was also of importance. In some vessels which he knew of, fitted with Mr. Howden's plan of forced draught, a considerably

higher power was obtained from boilers of only about half the weight and occupying only half the space; while not only was the cost of the second boiler saved, but a greater dead-weight carrying capacity was given to the ships, as well as larger stowage space. Moreover the complication and expense were avoided of a double set of feed, blow-off, and waste-steam pipes, and also of general boiler mountings and seatings; and the ships might be propelled at a higher speed. As one among many examples which might be given of the advantages derived in cases where that plan of forced draught had been applied, he might mention the s.s. "Clan Fraser," of 2,083 gross tonnage and 1,349 net, having triple-expansion engines with cylinders 22 and 34 and 59 inches diameter and 42 inches stroke. Steam at 160 lbs. pressure was supplied by a single boiler, 15 feet diameter and $11\frac{3}{4}$ feet long, with three furnaces of 3 ft. $7\frac{1}{2}$ ins. diameter, and 2,338 square feet of heating surface, and 50 square feet of grate area. As in several sister ships also, this boiler maintained over long voyages 23·66 indicated horse-power per square foot of grate, on a coal consumption of $1\frac{1}{4}$ lbs. per indicated horse-power per hour, the total power being 1,183 indicated horse-power. In respect of net tonnage there was nothing against the use of forced draught, but rather something in its favour when it was properly dealt with. In regard to the mode of applying the artificial draught to the boiler of the "Iona," he remembered that in 1886 the admission of the air both above and below the fire-bars had been advocated by Mr. Fothergill, who then stated that to admit the air wholly below the bars was to run a great risk of bringing them down. In the "Iona" however that view had been departed from. When the air was distributed in a proper manner and proportion both above and below the fuel, the bars lasted for a long period without injury. Only today he had been on board a ship which had made three round voyages to the East under Mr. Howden's forced draught, and not a single bar had been injured during the period occupied by these voyages.

There was no doubt it was hardly fair to take the temperatures of the waste gases at the height at which they had been taken in the funnel of the "Iona," and then to deduct only the loss due to those

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temperatures. If they had been taken at the usual place, namely at the top of the smoke-box, the loss by the escaping heat would have come out much greater: if he understood aright the observations in the "Meteor," the "Fusi Yama," and the "Colchester," the losses due to the escape of waste heat were great in those vessels also.

Mr. J. Macfarlane Gray thought the Committee's experiments were proceeding very well, and the series was becoming highly valuable. With regard to the calorimetric tests made by Mr. Legros with the beautiful Thomson calorimeter exhibited, he asked whether the correction for the latent heat of the steam formed in combustion had been deducted. If it was not deducted, and if the smoke-box temperature of 672° in Mr. Fiddes Brown's experiment was accepted and was assumed to be the temperature in the Committee's experiment, it would be found that the 14·6 per cent. of heat which had not been accounted for (page 214) would be greatly diminished. That correction would take away 3 per cent., and the error, as he believed it to be, of taking the temperatures so high up in the chimney would account for 9·2 per cent., leaving therefore only 2·4 per cent. unaccounted for, which he thought was a remarkable result, and said a great deal for the care of the experimenters.

Although the quantity of steam required to drive the fan for the forced draught was but a small matter, he thought it was well that the fan was not driven by steam from the main boilers. For if the object was to see how the main engines worked, he thought that any steam which was spent in producing the steam for the main engines had nothing to do with the result, which depended solely upon what was done with the steam after it had been produced; and therefore the mode of stating the result was better as it was given in the report. From an experiment made upon Mr. Willans' engine he understood an efficiency of 82 per cent. had been obtained; and if the efficiency in the report had been calculated in the same way, it would have been raised from 69·2 per cent. to about 72 per cent. The present was the best marine example that had yet been reported in these trials; in the previous ships the engine efficiency had ranged from 62 to 67 per cent. It was now up to 72 per cent.; and the engineers

who would make up the further 10 per cent. to overtake Mr. Willans' figures would be doing good service to steamship owners.

With regard to the funnel damper being never more than one-sixth open, he agreed in thinking that if the damper were opened wider the fan would perhaps not be necessary. Having asked Mr. Fothergill about this, he understood that his object in shutting the damper was to keep the gases as long as possible in contact with the heating surface. That was an explanation which he had frequently heard, but he had never been able to understand it; and he should be glad if it could be made clear how it was that shutting the damper kept the gases longer in contact with the heating surface. It appeared to him that the time during which the gases could be kept in contact with the heating surface must on an average be just exactly the time which was required for the fire to produce the quantity of gases which would fill the space between the incandescent fuel and the damper. If so, what would the closing of the damper do? It increased the density, and to that extent no doubt it prolonged the time; but the prolongation must be extremely minute. Taking the higher ashpit pressure of 0·32 inch of water, measured in the chief engineer's trial (page 216), this trifling increase upon the atmospheric pressure, which was 34 feet or 408 inches column of water, represented only 1-1,200th part of the time, and was equivalent to compressing three seconds more into every hour. As the ship's speed was only eight knots, it seemed to him that, if the fan were done away with and those three seconds per hour were added on at the end of the voyage, it would make but little difference in the time of the vessel's arrival at her destination. The idea of retardation by closing the damper he thought might probably be due to a philological confusion with the retarders used in Mr. Howden's highly successful plan of forced draught. Here the damper was merely retarding the gases, and only to the minute extent just mentioned; whereas in Mr. Howden's plan it was not the gases that were retarded, but the heat. The latter plan was equivalent to securing a large increase of heating surface, because the action of the heating surface in the tubes was by conduction alone, as regarded the gases: that is, the heat was imparted to it by contact with the gases. The tubes were also

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receiving heat by radiation from the smoke or the solid matter that was in the gases. In Mr. Howden's plan the retarders were pieces of metal, which were inserted into the tubes and took the heat out of the gases: they not merely exposed an increased extent of surface to contact with the gases, and received the heat from them, but they were also heated a great deal hotter than the surface of the tubes, because the tubes had water on the other side, and the retarders or rather radiators had none; they picked up the heat, and then threw it out by radiation to the tubes. It appeared to him that the reception of heat by the heating surface of the tubes was thus carried on in these two ways simultaneously; one did not interfere with the other. If the tubes were receiving heat only by conduction from the gases, there was a certain limit to the rate at which the evaporation could go on; but if at the same time heat were also poured upon them by radiation, they would take up the latter too, and it would not interfere with that received by conduction; the tubes would take up both, and they thus got their heating surface virtually increased in value. In reality therefore the retarders which were put into the tubes, and which he understood answered well, were equivalent to additional heating surface; and if they became burnt away it did not matter, for these radiators did not require to be water-tight.

Mr. John G. Mair-Rumley, Member of Council, was sure all the members would feel equally indebted with himself to Professor Kennedy for so kindly giving them the advantage, not only of his advice in regard to the conduct of these trials, but also of his personal attention in carrying them out. So careful an experimenter as he was must have had good reason for omitting the small corrections pointed out by Mr. Mudd, or he would have taken notice of them in the usual course. There could be no doubt that the engines and boilers of the "Iona" were unusually large for their work; and he thought it was a good thing that they were, because this experiment was in consequence one of the most interesting that could be made, for comparison with such engines and boilers as those in the "Meteor." In comparing these two trials, it was of

course necessary to separate the boiler from the engine. About the boiler he had nothing to say, except to refer to the difference of size, as already pointed out by Mr. Marshall (page 237): in the "Iona" each square foot of heating surface evaporated only 2·73 lbs. of water per hour, while in the "Meteor" it gave 4·49 lbs., or almost double. But the most interesting matter was in connection with the engine. Looking at the combined diagram which Mr. Mudd had kindly prepared, Fig. 26, Plate 53, it would be seen that the range of expansion in the "Iona" engine was prodigious, amounting apparently to no less than nineteen times. In the "Meteor," with nearly the same boiler pressure, the total expansion was only about ten times. In order to see what gain there was from the larger ratio of expansion, the back pressure in the two cases must be taken into account. In the "Iona" the back pressure in the low-pressure cylinder was only 1·84 lbs. per square inch above perfect vacuum, showing that the condensing apparatus was most efficient; in the "Meteor" it was 3·3 lbs. Had the latter been the same as in the "Iona," namely 1·84 lbs., the "Meteor's" mean indicated horse-power of 1,994 would have been raised to 2,088, and the comparison would be 254 thermal units per indicated horse-power per minute in the "Meteor," and 249 in the "Iona," or rather less than 2 per cent. better efficiency in the "Iona." This he thought was a curious result. Here were two triple-expansion engines, both of them carefully designed and made as well as they could be made by experienced builders; with about the same boiler-pressure and the same vacuum, one had nineteen expansions, and the other ten; and yet the former showed only 2 per cent. higher efficiency than the latter. So curious a result he was sure must cause every one to feel much indebted to Mr. Mudd for giving the opportunity of testing such a large engine working at such a small power, as was seen to be the case on comparing the weight of the machinery and the power developed; for the "Iona's" machinery in working order gave only 2·83 indicated horse-power per ton, while that of the "Meteor" gave 4·78 horse-power per ton, making allowance for the weight of shafting, tunnel bearings, and propeller. One of the reasons given by Mr. Mudd (page 230) why the results

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were so good was that the high-pressure cylinder was so well jacketed. But on this point he must join issue; for if that cylinder had been well jacketed, the water draining from the jacket, instead of being only 4·3 per cent. (page 210), would have reached, as Mr. Halpin had pointed out (page 248), from 12 to 16 per cent. of the total feed: in fact the more the better. The insufficient jacketing could also be seen from the amounts of initial condensation shown in the table in page 215 of the report: there it would be observed that the initial condensation was greater in the low-pressure cylinder than in the high-pressure; whereas if the engine had been well jacketed there would have been less condensation in the low-pressure cylinder than in the high-pressure.

The question raised by Mr. Macfarlane Gray (page 261), about the closing of the main damper, was a curious one. A large amount of fuel had been saved in a mill that he knew of by bricking up the flue until the opening into the chimney was only about 12 inches square, because the draught had previously been so much too strong. In making trials of pumping engines, the first thing done was to close the main damper as far as was compatible with getting sufficient air through. There was no doubt that somehow or other a much better boiler result could be got by having the main damper well closed.

The fact that the indicator pipes were long in the trial made by the chief engineer had been commented upon by Mr. Halpin (page 252). But it was upon the size of the pipes that everything depended; and he thought there was no harm in having a reasonable length of pipe if only it were large enough in diameter. In taking diagrams from a vertical cylinder of 5 or 6 feet stroke he had used a single indicator fixed midway, with pipes leading to it from each end, and a two-way cock for taking diagrams alternately from top and bottom; and he had found no difference from diagrams taken direct from the cylinder ends, because the pipes were big enough and the bends easy. If small pipes were used, they certainly should not be long. Before condemning indicator pipes merely on account of their length, he thought it should be borne in mind that if they were at the same time large enough in diameter there was not the harm that was generally supposed in having them long.

The importance of these trials he thought might be best judged by the interest which the members of the Institution and also the outside public had taken in them. It was a great source of pleasure to all the members to know that the Institution had originated such trials; and that many of the members had been anxious to do their best to assist in every way in having them properly carried out was shown by the list given in page 219 of the staff of observers.

Mr. E. G. Constantine observed that in the first trial the mean boiler-pressure was 165 lbs. (page 220), and in the subsequent trial 162 lbs., or 3 lbs. less. The mean admission pressure in the high-pressure cylinder however was 142½ lbs. in the first trial, or 22½ lbs. less than the boiler pressure, while in the second trial it was 147·8 lbs., or only 14·2 lbs. less than the boiler pressure. He should be glad to know whether that was attributed to the 29° higher temperature of the outer air in the second trial preventing radiation and condensation. Then again in the first trial there was a mean effective pressure of 20·44 lbs. in the intermediate cylinder, with a mean effective pressure in the high-pressure cylinder of 46·65 lbs.; whereas in the second trial the mean effective pressure was 0·23 lb. less in the intermediate cylinder, though it was 0·68 lb. higher in the high-pressure cylinder. It seemed natural to imagine that a higher pressure in the first cylinder would mean a higher pressure also in the second. A similar discrepancy between the two trials would be noticed on comparing the intermediate and the low-pressure cylinder. It would be interesting to know whether the engines were linked up differently in the two trials, or whether these differences were owing to the length of the indicator pipes in the second trial, and what was the diameter of the pipes; and also to have a set of diagrams from the second trial, for comparison with those taken in the first. [See Figs. 19 to 21, Plate 50, added accordingly from the second trial.] The excellent vacuum in the condenser seemed to him from his own experience to be rather abnormal; and he concurred in the opinion of Mr. Halpin (page 248) that it would be a great advantage to have some idea of the quantity of circulating water passing through the condenser, because he noticed that in the first trial the

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temperature of the circulating water was more than 20° lower than in the second, while the temperature of the discharge water had been raised in the second trial to the extent of nearly 4° less than in the first: which would appear to indicate that a larger volume of water must have been passed through the condenser in the second trial, because the vacuum had dropped only 0·12 lb. below that in the first.

For heating the feed-water it appeared to him a decided advantage to utilise the hot water draining from the steam-jacket and from the steam-pipe and valve-chest, if the heat contained in this water would otherwise be wasted. This explained how in the second trial it had been practicable to get a temperature so high as 157° in the feed-water, and yet to maintain a vacuum of so much as 13·76 lbs. below the atmosphere. It seemed to him matter of surprise that more attention had not been generally paid in marine boilers to heating the feed-water. Why should it not be carried to a greater extent than it was? not necessarily by means of live steam; but why could not the funnel gases be utilised for this purpose in the same way that they were ashore in stationary boilers? As to keeping the damper only one-sixth open, he could confirm Mr. Mair-Rumley's remarks (page 264) as to the advantage of not having the damper fully open, because he had come across boilers in Lancashire where there had been an intense draught, and when the damper had been closed to such an extent as to give a fair draught better results had ensued than when boilers had a draught of the same velocity with a smaller chimney and the damper full open. It was a peculiar fact which he could not satisfactorily explain; and he should be very glad to hear the explanation from those who had had the means of studying the matter.

Like other speakers, he thought the Members were all greatly indebted to the shipowners and superintendents who had placed their steamers at the disposal of the Research Committee, and to the Committee and the engineers of the vessels for the endeavours they had made to investigate these matters, and for the highly valuable information furnished in the reports and the accompanying tables, which would well repay the trouble of studying them carefully.

Mr. L. Alphonse Legros, having been one of the observers in the trial of the "Iona," in which he had relieved Mr. Burstall at the end of the first watch, recollected being with him at the beginning also; and, though he had not observed the amount of the supplementary feed, he had noticed that there was some leakage from the main feed-pump glands during the first hour and a half, but this had been diminished by their being screwed up. There was also during the last four hours of the trial a slight leak from the cock at the bottom of the measuring tanks; but he thought the quantity which escaped there was not more than a few drops in a minute. For the chance that either of the two gauge-glasses on the measuring tanks might get broken in the trial (page 253), there were spare glasses alongside; and he thought it would not have caused much disturbance to put a new one in, as there were fifteen minutes during which either tank was emptying or filling.

The modified form of the Thomson calorimeter was now exhibited with which he had obtained the result mentioned in the report (page 205). The original Thomson calorimeter had been considerably altered by Messrs. Donkin and Holliday; and their arrangement of gauze screens for breaking up and absorbing the heat from the products of combustion was here replaced by a different mode of bringing the gases into contact with the water in the instrument. When Mr. Wilson had prepared a sample of the coal for analysis, he had been kind enough to send him a specimen, which he put through the calorimeter in two portions; the calorific value obtained from the first portion was 14,870 thermal units, and from the second 14,910, the two results thus coming very close together. These determinations had been arrived at before the result was known of the chemical analysis of the coal. Another test of the same coal, made yesterday, had given 14,950 thermal units. But there had been a difficulty in calibrating the instrument, because he had not known what was the best material to use as the standard. Some chemists considered carbon obtained from sugar was the best to use, and others recommended other forms of carbon. If the carbon used were as pure as that on which the calculation from analysis was based, the instrument he was confident would always give a result within

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½ per cent. of that arrived at by analysis. The coal put into the calorimeter contained the moisture mentioned in the analysis, the sample not having been dried before testing; therefore the heat measured in the instrument would be the total heat that would be evolved by burning the coal as used in the boiler furnace, and a correction would be required for the heat lost in evaporating the moisture. The calorimeter consisted of two glass jars A and B, one inside the other, as shown in Fig. 37, Plate 59; the inner A contained the water in which the cage C enclosing the coal was immersed, Fig. 39; and the outer jar B formed an air-jacket surrounding the inner, the air being confined between the two by an india-rubber ring at top and bottom. The weight of water put into the inner jar was 2 kilograms or 4½ lbs. The weight of water equivalent to the metal and glass subject to change of temperature, taking into account the specific heats of the different materials, was added on to this, thus making the total weight on which the final calculation was based about 5 per cent. more than the weight of water contained in the apparatus. The coal charge of about two grammes or 30 grains was put in a platinum crucible U, hung in a platinum frame, and placed in the cage C. As soon as the charge had been ignited with a small fuse, a glass diving bell L was put down close over it; and by supplying the bell through a tube T with oxygen under a slight pressure the combustion could be conducted actually inside the surrounding water in the jar A, while it could be watched and regulated from the outside. The products of combustion passed down through a coil of four small copper pipes P underneath the cage C, from which they escaped into the water through four small perforations or nozzles N, Figs. 38 to 40; the heat was thus absorbed by the water from the gas bubbles passing up through it, which kept it in circulation, so that it was all raised to a nearly uniform temperature throughout. After the combustion the crucible was still hot; then by diminishing the pressure in the oxygen holder the water could be let into the bell to cool down the crucible; after which the water thus heated was driven out of the bell and mixed up with the bulk of the water in the jar by

blowing a little more oxygen through: so that there was no loss of heat left behind in the interior of the calorimeter. Although it would take a long time for any heat to radiate outwards through the air-jacket, yet in order to obtain the result with the greatest accuracy, it was necessary to take simultaneous observations of the temperature of the water in the instrument and of the room. The time was noted that the experiment lasted, which was generally from ten to fifteen minutes; and the difference being known between the temperatures, both of the room and of the water contained in the instrument, at the beginning and at the end, it could be found how much greater the radiation had been outwards to the room than inwards from the room, provided that the rate of radiation for a given difference of temperature was known. By leaving the instrument exposed in the room at a known difference of temperature for a considerable time, a factor representing this correction for radiation could be obtained. In ordinary working it was convenient to take about 30 grains of coal, because a charge of this weight would produce about 8° C. or 14° F. rise of temperature in the water. Then if the water were about 7° F. below the temperature of the room at starting, and about 7° above at the end of the test, the correction for radiation was extremely small. In his first experiment he had observed a rise of 15° F.; and the radiation correction amounted to only 0·07° F. Then again, as not quite all the heat was absorbed by the water, there was an empirical correction to apply; and this he had arrived at in the best way that he could think of, by trying the instrument with Nixon's Navigation coal, of which he knew the analysis. The empirical correction thus arrived at consisted in an addition of 0·3 per cent. to the result obtained by the observation of temperature after it had been corrected for radiation.

Mr. Charles J. Wilson said it was only at the last moment before the "Iona" trial that the idea had occurred of endeavouring to determine the priming. The apparatus employed was not originally intended for that purpose, and was not altogether suitable; and hence it broke down. Priming he thought must always be a question of quantity; for he could not believe it was possible to

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have a boiler so constructed that absolutely no priming should take place, that is, that no particles of water should be carried over by the steam in a liquid instead of in a gaseous form. The amount of priming in the "Iona" trial was no doubt exceedingly small.

For determining the calorific value of coal, the most accurate method known to science at the present time was by means of the calorimeter devised long ago by Favre and Silbermann, and since modified and made suitable for use with ordinary coal by Scheurer-Kestner. Next to a determination by the Favre and Silbermann instrument, the best way of arriving at the calorific value of coal was undoubtedly by calculation from a properly made chemical analysis of the coal. The latter was the method followed in the present as in the previous trials. Comparison of the results obtained by means of a Favre and Silbermann calorimeter with the heat value calculated from the analysis showed that the two methods gave fairly concordant results. The calculation was made on the obviously justified assumption that the water contained in the coal was evaporated as steam; and that the hydrogen contained in the coal, after having undergone combustion into water, was also carried away in the form of steam.

With regard to the height at which the temperature of the funnel gases had been taken, it must be remembered that on board ship it was not always practicable to put the thermometer and the collecting tube exactly where it would be preferred; but they had to be placed where it was found possible to put them; and in the "Iona" trial there were practical reasons why the temperature had not been measured quite so low down as might be wished. The greater the distance from the point of combustion, the lower would obviously be the temperature of the gases; and in this particular trial the temperature of the funnel gases was taken after they had perhaps lost a sensible amount of heat by radiation. This however did not affect the composition of the gases in the least; and as the analyses showed, the combustion that went on during the trial could not well have been better. The amount of carbonic acid was uniform in all the samples, and was high; while the combustion was carried out in such a way that not any carbonic oxide was found to be escaping.

In this trial he had deviated from the method employed in the previous trials, inasmuch as the gas samples had here been taken for the most part continuously, instead of at intervals, in deference to a wish expressed in the discussion of the previous trials, though he did not himself attach any great importance to the change. In the former trials, the tube used for conducting the gases out of the chimney was so large in capacity, and the vessel in which the samples were taken was so small, that it was a matter of no consequence whether the samples were drawn off rapidly or slowly, because the sample taken would represent only the contents of the tube for the time being. In the "Iona" trial however an exceedingly small tube had been used, through which the gas had been drawn off so slowly that the sample taken did really represent gas drawn from the chimney during the lengthened periods recorded in Table 9 (page 209).

Mr. Edward B. Marten, Member of Council, though having nothing to do with marine boilers, had often listened with great interest to what had been said by marine engineers about what duty could be done by such boilers, and had been led to fancy that there must be a great deal of exaggeration. The Institution therefore he thought was greatly to be congratulated on having such a careful test as the present for showing exactly what the actual duty was. It was also highly gratifying to see how much the results of the earlier trials had been confirmed by those of the later; and it was interesting to learn from the appendix to the report (page 219) how many of the members of the Institution had lent their aid for carrying out the experiments so thoroughly, which without their help could not have been done with the same amount of care. No doubt Professor Kennedy had obtained a good duty out of these engines; but the Institution he thought had got a better duty still out of Professor Kennedy, who had himself worked so hard at this subject, and had in every instance brought all the calculations and results into the fierce light of criticism in the discussions upon these reports. Being himself so much interested in boilers generally, he heartily concurred in Mr. Willans' terse remark, which was so much to the point: namely that it would be better to make the boilers much larger and

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work them slowly, and to work the engines as fast as they could be driven. With land boilers he believed it had generally been found to be the case that the slower they could be worked, within reasonable limits, the better was the efficiency obtained. This however he had thought to be utterly inadmissible with marine boilers, on account of not being able to get space enough; yet in the course of the present criticisms only one speaker (page 258) appeared to have alluded to such an objection. So far as had at present been learnt, there seemed to be no complaint on the part of the owners of the vessel that the boilers were so large; and he presumed therefore that in other vessels afloat the present boilers might even be replaced by larger, and their efficiency be thereby increased.

Mr. John R. Fothergill, referring to the large size of the boilers in the "Iona," pointed out that the ship was what was called an extended or long-bridge well-decked cargo vessel; and when completely filled with ordinary cargo, such as coals, she was not down to her loading-line draught, and therefore could not carry more cargo, even if the boilers were only half the weight. With a dead-weight cargo, such as iron, the result would of course be different; but dead-weight cargoes were the exception with the "Iona." Under the ordinary measurement rules, the machinery space was required to be 32 per cent. of the whole; thus no space would be saved for cargo by smaller boilers. To any objection urged against the size of the boilers and the engines the answer lay in the results obtained, which he thought would be admitted to surpass any that had hitherto been placed before the Institution. The dead-weight cargo of the steamer when fully loaded was usually 3,075 tons, and she maintained an average speed of 8½ to 9 knots on a coal consumption of 1·39 to 1·41 lbs. per indicated horse-power per hour. It should be borne in mind that this speed was not over a measured mile only, but was the average speed obtained by dividing the total distance by the whole of the hours steaming. That was a different thing from running a ship with 900 or 1,000 horse-power and making ten knots on a measured mile. The true speed of a ship he considered was the mean speed over the whole voyage; and taking

into account the three factors—speed, tonnage, and coal consumption —he doubted whether there could be found any steamers of the same class doing better work or even equal to that performed by the "Iona." There had not been the means of testing the efficiency of the boilers under natural draught in comparison with forced draught, because they had been arranged entirely for forced draught, and being so fitted could not be altered to work with natural draught for the purpose of a trial. If the boilers had not been designed for forced draught, it would have been necessary to have three furnaces in each boiler, in order to obtain the grate area required for the ordinary conditions of natural draught. Fifteen other steamers were running, so fitted for forced draught, several of them being old boats that had been altered; and the results had been so satisfactory that he had gone on altering. The advantage of closing the damper to such an extent appeared to him to be twofold. The slight compression thereby produced was sufficient to have the effect of bottling up the gases and bringing them into closer contact with every portion of the heating surface; and at the same time of promoting a better union of the gases themselves, and a more complete combustion. The analysis of the funnel gases showed more complete combustion than in the other trials previously made; and it was a fact that if the damper was opened full the steam could not be maintained the same as when it was partially closed. If the funnel damper had been set wide open, the small volume of gas produced by the small quantity of coal consumed would under the funnel draught have passed through only a portion of the tubes, and would not have come in contact with the whole of the heating surface of the combustion chamber; and thus a large portion of the heat of the gases would have been lost, because gases did not give up heat by radiation, but by conduction. With forced draught the closing of the damper all but one-sixth was a different thing from the same extent of closing with natural draught, because in the latter case there would not be draught enough to keep the steam up. There would have been considerable difficulty in putting the pyrometer down at the smoke-box; for taking the observations in that position it would have been necessary to rig up special stages. But he had

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no doubt that the temperature of 672°, noted in the subsequent trial made by Mr. Brown, might be taken as about the temperature of the gases leaving the tubes. Even in the smoke-box the temperature was probably different at the top tubes and at the bottom tubes; and it might be difficult to get the true mean temperature of the gases, unless it were measured at some distance beyond the smoke-box; even then allowance would have to be made for radiation, which he did not see the means of arriving at.

By lengthening the grate-bars to 5 or 5½ feet (page 254), 800 to 900 horse-power could be maintained without difficulty. But this was not wanted; the boat was running economically in regard both to coal consumption and to speed; the owners were satisfied, and wanted no more. If it was wanted to run at a higher speed on any particular voyage, it could be done. As to the funnel being too large, there was no back-door at sea; and suppose the fan were to break down, the large funnel would allow of opening all the ashpit doors and opening the damper wide, and running with the natural draught, without much reduction in speed. On that account the funnel of 6 ft. 3 ins. diameter had been preferred to one of only one-sixth the area, or say 2 ft. 6 ins. diameter. In the first steamer to which he had applied forced draught, now about six years ago, the air had all been admitted at the front of the furnace, above the fire-bars as well as below. But subsequent experience had led him to believe that better results could be obtained by not supplying air at the furnace front above the fire-bars. If air under pressure was supplied there through straight holes in the baffles, it passed along the furnace crowns, chilling them; and to prevent this with a short fire-grate it was necessary to converge the air more or less to a focus on the fire, with the production of intense local heat which was dangerous in its effects. But when the air entering at the front of the furnace was admitted below the bars only, the whole advantage was obtained of the radiated heat from the fire, which was taken up by the furnace crowns. The carbonic oxide after passing over the fire-bridge was thrown down by the deflector plate to the bottom of the combustion chamber, into which a further supply of air was now admitted at the back; and on looking in through the sight-hole under the bridge the

flames could be seen almost touching the bottom of the chamber. As shown by the water-gauge readings given in the report, the air going in at the back was at a higher pressure than that entering the ashpit, in consequence of the back admission being so much nearer to the fan. The entering air was broken up into jets or streams, which penetrated the gases, and acted as a sort of air poker to stir them well up, so that there was a thorough intermingling and complete combustion. The arrangement was like an argand burner, and there was no chilling effect. The deflector plate he considered was of great value. The gases were thereby thrown down to the bottom of the combustion chamber, and filled the whole chamber completely before they passed thence into the tubes; and the damper being nearly closed, the full benefit was gained of every inch of heating surface. The length of the fire-bars depended largely upon the trade in which the ship might be engaged. The usual voyages of the "Iona" were to India, and those who had to do with steamers making Indian voyages knew well enough that they could not always choose their coals when they got to the other side of the Suez Canal, but they had to take what they could get and be thankful; hence they could not run their steamers with as small a grate as they could if they knew that they could always get coals of good quality. Steamers constantly employed in the home trade with coals obtained at home could run with the greatest ease with a fire-grate only 2 ft. 6 ins. long; one of the boats under his own charge was running with a grate of only that length. As to the life of the fire-bars when forced draught was employed (page 259), the bars he was using were deep and narrow, and some had been at work for two years without renewal. There was no difficulty with them, and he had never yet had a set burnt down. In his early experience with forced draught he had had much difficulty in obtaining a fan and engine to do the work on board ship, and had tried friction gear, ropes, and belts, but all to no purpose. The Chandler engine and fan however he had found a most successful combination. In another boat he had one of these engines and fans of the same size as that in the "Iona," and it was running constantly at 500 revolutions per minute for thirty days continuously in the Indian trade, and had

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done so for nearly three years with perfect satisfaction. He saw no objection whatever (page 245) to the closed-in engine; in fact he used nothing else at present, and he had some fourteen in use. In the furnace he used a side fire-bar, which was packed with asbestos so as to make an air-tight joint between the furnace side and the side bar (page 245), thereby preventing any supply of air to the fire in contact with the furnace, and thus reducing the intense heat at that part; this he had done for some time with beneficial results.

The mean indicated horse-powers given in Table 12 (page 227), he wished it to be clearly understood, were not trial-trip horse-powers, but were the mean powers developed over the whole of the respective voyages. Too frequently ships were spoken of as going 10 knots and burning a remarkably small quantity of coal. As a matter of fact he had never been fortunate enough to meet with any of those extraordinary boats. It was true that his own boats would do their 10 knots in fine weather; one carrying about 4,300 tons, and running down the channel in fine weather, did her 10 knots without question; but taking her through her Indian voyages during eight years, and dividing the whole distance by the steaming time, the mean speed was $8\frac{1}{2}$ knots. What therefore was the use of calling her a 10-knot ship? And the same with the horse-power. The final column in Table 12, giving the coal consumption per indicated horse-power per hour after 10 per cent. had been deducted from the proportion of coal received abroad, showed a remarkably close agreement in the results of the four voyages of the "Iona"; and the closeness with which they also corresponded with the result of the trial constituted in his opinion one proof of the great value of this and the previous trials.

Mr. THOMAS MUDD said that, while the boilers of the "Iona" were capable of giving considerably more power if it had been desired, yet the essence of the trial had been to make it just as the machinery was in the habit of being worked at sea; and all who were concerned with cargo boats knew well that it was the custom to run them much within their power, and how important was a large reserve of power which could be used at any time when it was

desired either to run quickly for several hours to catch a tide, or to make a specially quick voyage with an exceptional cargo. If the trial had been intended to show what power could be got out of the machinery, it would have been quite a different thing; but the object was to see what the economy was under ordinary working conditions.

In reply to Mr. Willans' enquiry (page 243) whether a trial had been made without the steam-jacket in operation, so as to compare it with the trial made with the jacket in operation, no such trial without the jacket had been made. The jacketing of the engine was of a peculiar kind, especially from the fact that the high-pressure cylinder was in the middle between the other two, Plates 55 and 56. There were three walls of metal surrounding the high-pressure cylinder: the space between the innermost and the second was the jacket, and the space between the second and the outermost formed the receiver capacity. It was therefore obvious that, if the high-pressure steam were shut off from the jacket, it would be far better never to have had the high-pressure cylinder in that position at all, because it would still be surrounded by the outer jacket of low-pressure steam in the receiver, and naturally there would be a large transference of heat from the high-pressure cylinder into that receiver. The result therefore of any trial without the steam-jacket in operation he thought would not be of any real service for determining the value of the jacket by itself.

As to the difference between the supplementary feed plotted in Fig. 24, Plate 52, and that measured in the Committee's trial, the former was the result of a trial previously made by the chief engineer over a period of nine days; and it proved that the same set of machinery did not require so large a supplementary feed as that shown in the Committee's trial. In the latter it was agreed that some leakage had been noticed, but had not been measured; and therefore how much water would leak through in sixteen hours was a point on which opinions might easily differ. During the first hour and a half it was recorded that there was a considerable leakage at the feed-pump glands, and that afterwards it appeared to die away. Curiously enough however, as shown by the diagram of the supplementary feed

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in Fig. 22, Plate 51, it happened that during the first hour and a half of the trial scarcely any supplementary feed at all was put into the boiler, the line being there horizontal. A little was put in three quarters of an hour after the trial began; and then no more was put in until another hour had passed: so that it was an hour and three quarters before the supplementary feed began to be put in with any regularity. It would be observed from the diagram that the line continued pretty regular for a considerable number of hours, and then there was a little cessation because the feed was going in too fast; the boiler water-line rose about $1\frac{1}{2}$ inch in the gauge-glass, therefore less supplementary feed was put in: after which it again continued to go in at about the same rate as before. Everything connected with the supplementary feed therefore went to show that there was some leak fairly continuous: by which he did not wish to imply that he was not satisfied with the results of the trial, but he was simply trying to show that in this respect they were rather better than they looked, and that in regular working the engine never required anything like 6 per cent. of supplementary feed.

In reply to Mr. Phillips' enquiry in this connection (page 257), the supplementary feed in this case was salt water drawn from the discharge of the circulating pump, and after being separately measured was allowed to be sucked into the condenser by the vacuum, thus becoming mixed with the general hot-well water, and re-measured with it in the big measuring tanks before reaching the feed-pumps. It therefore got no heat from the donkey boiler.

With regard to wire-drawing (page 255), the general opinion at which he had arrived was that there was economy, to some small amount at all events, in wire-drawing between the boiler and the engine. In the trial it would be observed that there had been a drain from the steam-pipe and another from the high-pressure valve-chest, and that both together gave only a small quantity of water, much less than the quantity deduced from Mr. Wilson's one solitary experiment; the latter accordingly showed that there was more water in the steam than was coming out of the drain-cocks. All this went to show that there was a kind of priming which might be regarded as moisture mixed entirely throughout the steam like a

fog; and whether the economy observed on closing the stop-valves resulted from keeping that moisture back in the boiler, or simply from the drying and superheating of the steam on its way from the boiler to the engine, was more than he could tell. In the trial the stop-valves were much closed, according to the usual practice at sea; and the engines were much linked up, the same as in their ordinary running.

With regard to the suggested desirability of having an indicator diagram taken from the lower side of the air-pump bucket, it should be explained that in this engine there was no foot-valve: so that the under side of the air-pump bucket was exposed always simply to the open condenser. Therefore, although no such diagram had actually been taken, he thought it could be little else than a horizontal straight line, except just at the particular time when the bucket struck upon the water collected beneath it. The condenser diagrams mentioned in the report (page 212) had been taken higher up.

The interesting point to which attention had been called by Mr. Phillips (page 255)—namely that the indicated horse-power did not appear to follow either the pressure or the revolutions, or anything else to which it might be expected to bear a direct proportion—had been noticed by himself more than once, but he had not yet succeeded in finding any explanation to account for it, if indicators were to be depended upon for giving identical indications when like conditions existed in the cylinders. In the record of the trials the variation was not nearly so great as he had noticed at other times; in the Committee's trial there was a total variation of as much as 40 between the highest and the lowest indicated horse-power (page 211), and of 46½ in the chief engineer's trial (page 216); and there seemed nothing to account for it. It was a common thing to observe; and the only suggestion that had occurred to him was whether there might possibly at certain times be a little water that had gradually collected in the cylinder, and whether for some reason or other it might chance to become evaporated into steam in some one particular stroke, and so produce a bigger diagram for that stroke, without any corresponding change having occurred either in the speed of revolution or in the initial

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steam-pressure. Whether that might be the explanation or not, it was at any rate interesting to call attention to the fact that the maximum indicated horse-power given by any one set of diagrams in the Committee's trial was 667·9, which coincided with 61·3 revolutions per minute and a boiler-pressure of 163 lbs.; whereas the minimum of 627·5 indicated horse-power, or 40 horse-power less, was coincident with 61·4 revolutions and 162 lbs. pressure, that is, practically the same speed and pressure as for the maximum power.

With regard to the steam for the fan-engine, he was glad to hear what Mr. Gray had said (page 260) about its being better not to complicate the result by taking the steam from the main boilers for this purpose. That was a question which had been considered and discussed beforehand with Professor Kennedy, who had agreed that the best plan was to use the steam from the main boilers for the main engines only, in order to ascertain what the engines were really doing.

In Mr. Fothergill's Table 12 (page 227) the allowance of 10 per cent. deduction from the proportion of coal received abroad had been referred to (page 256) as sufficiently accounted for by the inevitable loss always attending the handling of coal. The true explanation however was that the 10 per cent. was deducted simply because it had never been received at all. In England it was true that the full weight paid for was obtained; but it was unfortunately too well known by shipowners that, if they had to buy coal further from England than Gibraltar, the probability was that the quantity received would not be within 15 per cent. of what was paid for. In such cases therefore it would be only misleading to take the weight paid for as representing without deduction the vessel's actual consumption.

That the economy in the trial was largely accounted for by the good quality of the coal (page 258) he could not admit, for the good reason that the economy was calculated upon the carbon value of the coal, just as it had been in the previous trials; and he did not see that the result was affected in the way suggested by the circumstance of the fires requiring less frequent cleaning when better coal was used.

With an expansion of nineteen times in the "Iona" it had been pointed out by Mr. Mair-Rumley (page 263) that there was only 2 per cent. better economy than in the "Meteor" with only ten expansions. It was an interesting fact to note that the expansion could be carried so far as nineteen times, even though with so small an increase of economy, because it was considered by many engineers that so large a number of expansions must necessarily be uneconomical.

The differences pointed out by Mr. Constantine (page 265) in the relation of the various pressures were accounted for by the circumstance of the engineer having set the engines slightly differently: there was link-adjusting gear on each of the three engines. The drawing of the pistons, asked for by Mr. Halpin (page 249), he should be glad to furnish, as well as a complete drawing of the cylinders showing the jacket. [See Figs. 28 to 31, Plates 54 to 56.] The piston rings were of square cross section, Figs. 28 and 29, Plate 54, and their size was 2 inches square for all pistons from 18 inches up to 80 inches diameter, thus covering with one size a large range of engines in which the same size suited all the cylinders. The cross section 2 inches square gave a large bearing surface on the junk ring and the piston flange, enabling the rings to have a good grip on these bearings, without wearing in and forming a ridge, which would necessitate re-bedding. The springs were mere short helical springs of one universal size: that is to say, the springs for all positions in any one piston, for all pistons in any one engine, and for all engines from small to large powers, were identical; and this universality of spring was of the greatest benefit in many ways. The spring pressures which regulated the force applied up and down between the junk ring and the piston flange, and the force applied tangentially pressing the rings against the cylinder walls, were each applied independently of the other, and could therefore be separately regulated in amount. The position of the vertical springs being precisely in the centre of the breadth of the rings, the force applied by them was fair and central on the bearing surfaces, thus not encouraging any rocking or twisting of the rings. The rings being so stiff required no springs whatever behind them against the

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piston body, and hence they partook of the quality known as floating: that is to say, in running up and down the cylinder they could follow the line of the cylinder, irrespective of where the piston might be; and the oscillation of the piston from side to side of the cylinder had no effect in putting more pressure on the packing rings at one side of the cylinder than at the other.

Professor Kennedy considered the discussion of the report had been highly suggestive on many points; and he would endeavour to supply the various additional items of information that had been asked for. Both Mr. Mudd and Mr. Fothergill had kindly dealt with a large number of matters regarding the design and construction of the engines and boilers, with which it was of course not within his province to deal. Mr. Mudd had also suggested numerous corrections that would more or less modify the recorded results of the trial of the "Iona." In common however with every one who had to do with experiments, he entertained the strongest objection to making corrections and allowances in actual results, or to substituting part of one experiment as a correction of another. A number of differences between the Committee's trial and the chief engineer's had been pointed out by Mr. Constantine (page 265); yet there were no reasons why both might not be perfectly correct, because the conditions of the two were different. As a matter of fact and of principle the two trials must stand each on its own merits. For instance, the allowance for difference of feed temperature between the two trials was not even in the nature of a correction at all. The weight of feed-water used was given, and its temperature, and the amount of the evaporation; and there was an end of the matter. If the temperature had been so much higher, any one could calculate exactly the difference in the amount of the evaporation; and the subsequent trial so accurately made by the chief engineer showed just the difference that would be expected: it was a strong corroboration of the Committee's trial, and theirs was an equal corroboration of his. But although the difference was naturally a change of great importance to Mr. Mudd as representing the average working in this particular, it was not a

correction in any sense of the word; and he regretted that the word "correction" had been used, because in its natural sense it had no meaning whatever in the present connection. It could not be too clearly understood, he thought, that the whole conditions of an engine trial or boiler test were so complicated, and so mutually interdependent, that from a scientific point of view it was absolutely inadmissible to take bits of two or three different trials, piece them together, and then say that the combination represented any reality whatever.

The supplementary feed-water was of course a much more important matter than the feed temperature. Here it was known that something had gone wrong, because there was no doubt either as to the actual quantity of supplementary water that was used in the trial, or as to its being much more than the average quantity used in an ordinary voyage, and much more than in the chief engineer's previous trial extending over nine days. Even during those nine days however it was seen from the diagram, Fig. 24, Plate 52, how much the quantity had varied. In the second day, for instance, the water-level in the boilers went down in the glass more than two inches in twelve hours, Fig. 25. That was only half a day out of the nine days, and it was just as likely to be right as any part of the diagram. Therefore it would not be fair to correct the large supplementary feed in the Committee's trial from this in the chief engineer's; the only right course was to report the actual quantity, and to say that it was obviously much more than the normal amount, though he did not know where it went. A great deal had been made of the feed-pump leakage. The first thing he did after returning from the trial was to plot out the supplementary feed and the correction for water-level; and he found to his great disgust that the quantity of the supplementary feed came out practically uniform all through the trial. That pointed to a uniform cause, but the feed-pump leakage was not a uniform cause; it occurred only during the first hour and a half, during which time it was a source of many qualms to all concerned, and their anxiety was not relieved until it was reduced within reasonable limits, apparently to less than one-tenth of

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what it had been before. He therefore did not feel satisfied that the feed-pump leakage was the cause of the high supplementary feed. In replying to Mr. Burstall (page 244), and again in page 278, Mr. Mudd had spoken as if the leak through the glands must have been very large and must have been continuous, because the supplementary feed was both. It seemed however to be overlooked that the connection between the two was entirely hypothetical. The only things absolutely known were that the gland leak was considerable for a short time only, and therefore was not uniform, while the additional feed was uniform. The only direct evidence therefore went to show that these two things were not connected, whatever might have been the cause of the abnormally large extra feed.

In the table in page 215, showing the percentages of water in the cylinders, all that was done was to give the percentage of the total feed accounted for by the steam in the cylinder: the remaining percentage of course included always the 4·91 per cent. of water from the high-pressure steam-jacket and the steam-pipe and high-pressure valve-chest drains; this could be subtracted, and the remainder would then be the percentage present in the cylinder as water.

With regard to the arrangement of the jacket, he remembered that, when he was a draughtsman on the Tyne in 1870 under Mr. F. C. Marshall, the first two compound engines ever constructed at Jarrow had jackets made in the same way, the high-pressure jacket being itself surrounded by the exhaust steam on its way to the low-pressure cylinder. He thought it probable however that the jacket was never used at sea in those days.

In reference to the temperature of the funnel gases, he thought Mr. Wilson's remarks (page 270) were much to the purpose. The temperature he considered ought to be taken at a point as low down in the funnel itself as was feasible; but in many cases, as in the present, this point turned out to be higher up than he could have wished. The temperature taken in the uptake might really have but little value, because the gas would there not be well mixed, and the temperature might be either considerably above or considerably below the real average temperature. The error due to want of

proper mixing of the gases at the point where the thermometer was placed he thought was probably greater than the error due to loss by radiation in a certain number of feet of chimney; but this was no doubt a matter of opinion and of degree.

As to the way of stating rate of transmission of heat, he did not agree with Mr. Halpin (page 251). The figure given in page 214—so many thermal units per square foot of heating surface per hour—was an absolute figure got from experiment. The figure proposed by Mr. Halpin involved an assumption as to the furnace temperature, which he thought had really no very definite meaning.

In reply to Mr. Phillips' question (page 257), the supplementary feed was allowed to run out of the tank in which it was measured, direct into the bottom of the condenser, and so was pumped through the feed measuring tanks into the boilers with all the rest of the feed water.

It would be interesting to know how the indicated horse-power had been measured over several voyages, from which the coal consumption referred to by Mr. Bruce (page 259) had been calculated.

In reply to Mr. Macfarlane Gray (page 260), the correction for the latent heat of the steam had in every case been made.

The President thought the Institution was to be congratulated on the interest and value of all the reports that had been read upon the subject of this important research. They would be of the greatest use he believed to engineers in designing marine engines and further improving them. All the Members he was sure would cordially join in a hearty vote of thanks to Professor Kennedy, and to the observers who had been associated with him in taking so much trouble to carry out the trial of the "Iona," and to obtain the voluminous data for enabling him to compile the present valuable report; and to Mr. Charles J. Wilson for all the work done in his laboratory. Also to the owners of the "Iona" Messrs. Herskind and Woods, and their superintending engineer Mr. Fothergill, and to the builders Messrs. William Gray and Co., and their manager Mr. Mudd, for the opportunity afforded for carrying out this trial,

(The President.)

and for all the facilities and assistance received from them in connection therewith.

Mr. Bryan Donkin, Jun., wrote that he had found a good experiment upon a Sulzer horizontal triple mill-engine, in which the sizes of the cylinders and the steam pressure and the total power were so similar to those in the "Iona," that he had prepared the following short tabular comparison, which he thought might perhaps be of interest :—

Engines both condensing.		Sulzer.	Iona.
Date of Trial		1889	1890
Cylinder diameter, high-pressure	inches	J 21·7	J 21·9
„ „ intermediate	inches	J 33·5	N 34·0
„ „ low-pressure	inches	J 49·2	N 57·0
Stroke, length	inches	47	39
Boiler pressure above atmosphere, lbs. per sq. inch		141	165
Revolutions per minute	revs.	65·5	61·1
Piston speed per minute	feet	516	397
Indicated horse-power, total	I.H.P.	615	645
Steam per I.H.P. per hour including all jacket water (including pipe water)		11·85 lbs.	13·35 lbs.
Steam per I.H.P. per hour including all jacket water (excluding „ „)		11·70 lbs.	13·27 lbs.

J = Jacketed. N = Not jacketed.

Professor T. Hudson Beare wrote that he should be glad if Professor Kennedy would append to this report a table of the constants used in calculating the calorific value of the coal, and the mean specific heat of the furnace gases, and also add a reference to the various authorities for them. These being standard trials, it was

desirable to be able to compare the results with those of other trials, which could not well be done without this information. In the case of the "Iona," where the absolute quantity of steam condensed in the jacket &c. was known, it would also be useful if in the table on page 215 there were added the percentages of steam present in the cylinders, compared with the actual measured quantity passing to the engine from the boilers. From the way in which the jacket was arranged on the high-pressure cylinder, he should have expected a rather considerable superheating effect upon the steam in the first receiver; but the table on page 215 showed practically no such action. The jacketing indeed compared unfavourably with that of the "Meteor"; the much greater wetness of the steam in the low-pressure cylinder of the "Iona" was clearly marked, and seemed to point conclusively to the advantage of jacketing that cylinder.

Comparing the five trials already reported, he was much struck with the great variation in the proportions of the several boilers and the correspondingly small variation in their actual efficiency. The lowest efficiency was that of the "Meteor" and "Colchester" boilers, only 62 per cent.; the highest occurred in the "Tartar," namely 70 per cent., or a total gain of nearly 13 per cent.; yet the coal burnt per square foot of grate per hour varied from 11·93 to 26·10 lbs., a range of nearly 120 per cent. The other quantities varied equally as much; thus the proportion of heating surface to grate area ranged from 26·5 to 75·2; the horse-power developed per square foot of grate from 6·75 to 15·40; and the heating surface per horse-power from 2·94 to 6·08. Comparing the boilers of the "Tartar" and "Iona," having almost the same actual efficiencies, these variations were even more marked: a careful study of the figures gave apparently no relation between the various quantities; even such an important factor as the ratio of the heating surface to the grate area seemed to be indeterminate.

Professor Kennedy replied that the constants he had used in calculating the calorific value of the coal were as follows:—carbon 14,540 thermal units per pound; hydrogen 52,200 thermal units per pound. No carbon was burnt to carbonic oxide, so the corresponding

(Professor Kennedy.)

constant was not required. The hydrogen constant allowed for the fact that the steam formed passed away in a gaseous condition and was not liquefied. These constants were taken as the best values from Ostwald's *Verwandtschaftslehre*, which contained a critical summary of all the principal experiments on this matter.

MEMOIRS.

Alexander Allan was born at Montrose in 1809. After serving his apprenticeship to Mr. Gibb, millwright, at Lochside, near Montrose, he went in 1832 to Messrs. Robert Stephenson's, Newcastle-on-Tyne, and from there to Liverpool. In 1834 at the Vauxhall Foundry he assisted in putting upon the Liverpool and Manchester Railway Messrs. Forrester's first locomotive, the "Swiftsure," with its novel outside cylinders; and in the same year he was sent to Ireland with their three locomotives, which were the first introduced on the earliest of Irish railways, the Dublin and Kingstown. In 1840 he entered the service of the Grand Junction Railway Company at Liverpool, and later at Crewe as works manager and assistant locomotive superintendent, Mr. Francis Trevithick being the locomotive superintendent. At the new works at Crewe he was entrusted with the designing and construction of passenger and goods engines. In these original Crewe locomotives the outside cylinders were so arranged as to simplify the machinery; a straight axle having only two bearings, instead of a crank axle having four, allowed the boiler to be lowered; the size of crank pins and block crossheads was reduced; lighter connecting rods were adopted; and instead of eight slide-bars, as on all other engines at that time, four were used. In 1847 the "Velocipede" was built on the same design, but with 7 feet driving wheels; and this and other locomotives of similar dimensions were in use on the northern division of the London and North Western Railway until found too small for the increased traffic. The straight-axle locomotive was adopted by Mr. Joseph Locke in 1843 on the London and South Western and on the Paris and Rouen Railway. In 1846 the Caledonian Railway was supplied with designs by Mr. Allan; and in later years the Scottish Central Railway. In 1853 he left Crewe to be superintendent of the locomotive department of the Scottish Central Railway, extending to Perth, Aberdeen, Edinburgh, and Glasgow; and filled that post until 1865, when the line was amalgamated with the Caledonian. In 1854

he invented his straight-link valve-gear, in which balance weights and springs are dispensed with (Proceedings 1856, page 70); the gear requires less room, allowing the boiler to be placed lower; and during reversal the valve rod moves through one-third the space upwards and downwards, compared with the previous valve-gear. Between 1847 and 1885 he also introduced improvements in turntables; in tubular and locomotive and other boilers; in gas meters (Proceedings 1860, page 15); in locomotive retarding and stopping (1859, page 230); in buffer and draw springs; in land and sea batteries; and air-spring pressure-gauges (1859, page 179). For several years he was manager of the Worcester Engine Works Company, until ill health obliged him to retire from active work. In 1872 he went to live at Scarborough, where he resided until the time of his death on 2nd June 1891, at the age of eighty-two. He was one of the original Members of this Institution on its foundation in 1847; and contributed to the Proceedings other papers on his inventions besides those referred to.

JOHN WILLIAM COLE was born at Hetton in the county of Durham on 30th April 1840. He served his apprenticeship in the fitting shops of the Thornley Coal Co. at their large works near Hartlepool, where he acquired a good practical knowledge of winding, pumping, and underground hauling engines, besides locomotives, although the latter were of a primitive kind, including one engine with vertical cylinders. On the completion of his apprenticeship about 1858, he obtained an engagement as a journeyman in the locomotive works of the North Eastern Railway, York. In 1860 he went to Madras in the service of the Madras Railway, and was soon appointed resident agent and engineer at the Beypore terminus, having charge of a hundred miles of line. After six years of Indian service he returned to England, and became out-door manager to Messrs. Bells Goodman and Co., afterwards Bells Lightfoot and Co., with whom he remained till about 1880. One of the first works on which he was here engaged was to take down an old small blast-furnace at Walker-on-Tyne, and remodel and rebuild it on a larger scale. Other works consisted in the

erection and repair of chemical plant so extensively in use on the Tyne, besides engines and boilers for the coal and iron industries of the district. During this time he brought out a coal screen, which may be described as a Juckes furnace with screening spaces between the bars. At the end of 1880 he commenced business in London, and erected near Beckton the Horse Shoe Works, for manufacturing an invention which he had bought in America for the company owning the works. He was also concerned in the erection of machinery for chemical and manure manufactories on the Thames; and completely remodelled the machinery and appliances of a brewery near Coventry. In August 1882 he emigrated to South Australia, where, after having acquainted himself with surveying, levelling, and drawing, he was appointed to make a comprehensive survey of a district near Adelaide, for the supply of water to that city. The manner in which he carried out this work led to his being engaged by the Honourable James Martin as manager of his large engineering works, Phœnix Foundry, Gawler, where he was occupied for seven or eight years in the production of large hauling engines for mines, bridge and boiler work, and the arrangements for building forty-two locomotives for colonial railways. The anxiety incident to the latter undertaking in a distant colony was doubtless what brought on softening of the brain, which resulted in his death on 10th February 1891 at Gawler, at the age of fifty. In 1890 he left Phœnix Foundry, and obtained the appointment of inspector of machinery at the silver-lead mines of the Broken Hill Proprietary. He became a Member of this Institution in 1878.

Samuel Osborn was born at Ecclesall, Sheffield, on 21st August 1826, and on leaving school was apprenticed with Messrs. Thomas Ellin and Sons, and afterwards found employment with Messrs. Henry Rossell and Co. Commencing business on his own account in 1852 at Brookhill, Sheffield, he there manufactured chiefly files; and in 1869 he acquired in addition the more extensive premises of the Clyde Works in the Wicker, where he established himself as a steel refiner on a large scale, and became one of the foremost

manufacturers in Sheffield. He was elected Master Cutler in 1873. Severe adversities encountered in 1874 were honourably surmounted during the next ten years, and in 1884 he was able to add several other departments to the business. Having served for several years on the Town Council, he was Mayor of Sheffield at the time of his death, which took place at Blackpool on 7th July 1891, in the sixty-fifth year of his age, after an illness of several months. He became a Member of this Institution in 1870.

Robert James Ransome was born at Yoxford on 27th June 1830. He was educated at Ipswich, and on leaving school in 1845 was apprenticed to his father's firm, Messrs. J., R., and A. Ransome, agricultural engineers, Orwell Works, Ipswich; after which he became manager of the foundry department. In 1869 he joined his father and Mr. R. C. Rapier in establishing the Waterside Works on the opposite bank of the Orwell, for the manufacture of railway plant. One of their early works was building engines and laying down plant for the first railway in China. Besides the general business of supplying railway plant adapted to all countries, they constructed a great many cranes of large size for building breakwaters. The works now cover an area of eight acres, and employ five hundred men. He took an active interest in local affairs, and had been on the Town Council for twenty-one years. His death took place on 3rd June 1891, in the sixty-first year of his age. He became a Member of this Institution in 1862.

Charles Percy Bysshe Shelley was born at Epsom in 1827, his father being a physician and surgeon. After receiving his early education at Clapham and at King's College School, London, he received an engineering training in the applied sciences department of the same college under Professor Cowper. He was then engaged by Messrs. Fox Henderson and Co., Birmingham, upon many different works, but chiefly upon the designs for the ironwork of the Great Exhibition building of 1851; he also had the supervision of the firm's numerous pupils, whom he instructed in the theoretical part of their work. He next went to Mr. Thomas

Cubitt's brickworks at Burham near Rochester, where he erected a pair of 60 H.P. engines removed from the Croydon atmospheric railway. He was afterwards engaged at the Victoria Works of the Ebbw Vale Co., where he gave evening lectures to the men employed at the works, and made an extensive set of diagrams illustrating mechanical subjects. He next became chief assistant to Sir William Siemens, and then principal draughtsman to Mr. Edward Woods. For about five years he was in the drawing office of Mr. E. A. Cowper. He next fulfilled an engagement in Spain upon the Tudela and Bilbao Railway. He then established himself as an engineer in Westminster, and carried out the plans for the Thames Valley Railway, which subsequently became a branch of the London and South Western. In 1860 he became Professor of Manufacturing Art and Machinery in King's College, London, which position he held for thirty years, vacating it only about a year before his decease. He was for some time employed by Sir Joseph Whitworth, Bart.; and in conjunction with Mr. T. M. Goodeve he wrote a work descriptive of the Whitworth measuring machine. He was also engaged with Mr. J. S. Stokes upon the designs for an ironworks erected at Shrewsbury. For many years he was one of the assistant examiners in steam and mechanics at the Science and Art Department, South Kensington; and was also examiner in these subjects at the Royal Military College, Woolwich. He was the author of a useful book on workshop appliances, which was translated into Spanish. His death took place at Bromley, Kent, on 16th June 1891, at the age of sixty-four, after a short illness. He became a Member of this Institution in 1856, and in 1862 contributed a paper on the manufacture of hemp and wire rope.

Edward Slaughter was born in London on 1st December 1814, and having been educated at Ealing and in Paris was apprenticed for five years to Mr. John Seaward, Canal Ironworks, Limehouse, London. After two years of travel he became assistant engineer to Mr. I. K. Brunel in 1837, and took part in the construction of the London end of the Great Western Railway, subsequently holding a post at the Bristol end. In 1840 he became managing partner of Messrs.

Stothert Slaughter and Co., Bristol, specially with a view to the manufacture of locomotive engines. In 1866 the concern was converted into the Avonside Engine Company, of which he then became the managing director. In 1873 failing health induced him to abandon active work. When travelling abroad he devoted much attention to the peculiar conditions of foreign railways, on which steep gradients and sharp curves were largely employed; and as many of the locomotives were furnished by his firm, he took a prominent part in the introduction of the various bogie arrangements. He also designed and built two screw-steamers fitted with engines of the locomotive type, for running between Bristol and Newport, whereby the passage was greatly accelerated. His death took place on 13th May 1891, at the age of seventy-six. He became a Member of this Institution in 1853.

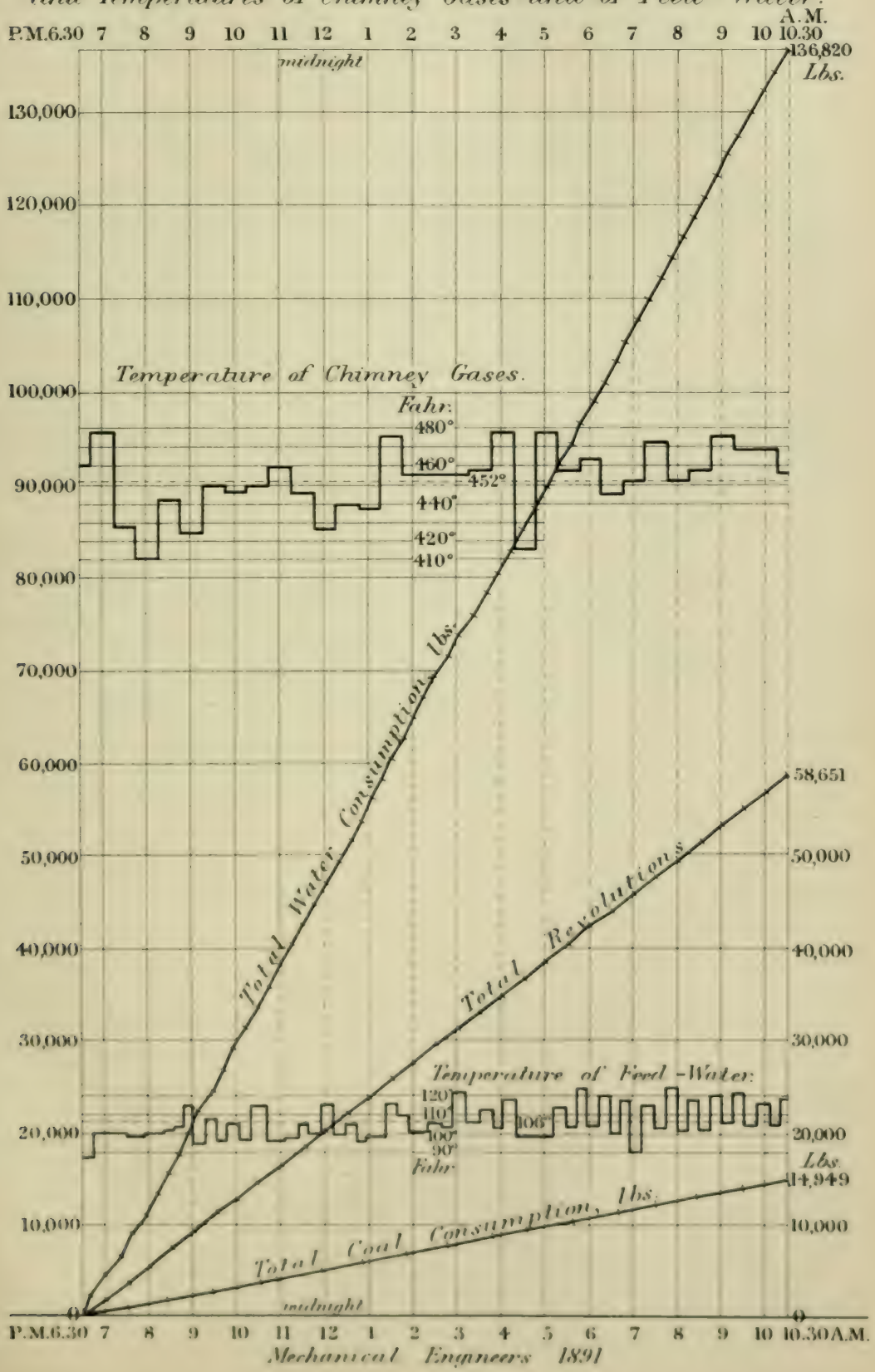
Benjamin Walker was born at Armley, near Leeds, on 20th April 1821. At the age of fourteen he was apprenticed for seven years to the engineering firm of Messrs. Newton and Taylor, Water Lane, Leeds; and at the age of twenty became foreman of a large shop. The greater part of his book learning he acquired during this time at a night school at Armley, where he worked so hard that on the expiration of his apprenticeship at the age of twenty-one he was a good mathematician, and had a considerable store of scientific knowledge. He was one of the first members of a literary society which was formed at Armley about 1838. Before he was twenty he had acquired such skill as a mechanic that his master used to send him to various mills in Leeds to put machines to rights when other men twice his age had failed to do so. In 1845 at the age of twenty-four he went to Belfast to be manager of the works of Messrs. Combe and Dunfield, afterwards Combe Barbour and Combe; but in 1847 he left these works, then in full operation and employing 300 hands, and returned to Leeds at a great pecuniary sacrifice to work as an ordinary engine-fitter, in order that he might devote his mind fully to the acquisition of mathematical and mechanical science, as he had found that having the direction of a large works prevented his gaining the knowledge he so much desired. Later on he became

foreman at Messrs. Kitson Thompson and Hewitson's works, Airedale Foundry, Leeds, and afterwards manager; and in 1851 invented several appliances for making forgings at reduced cost. In 1860, in conjunction with Mr. Hewitson, he introduced an ingenious self-acting motion for double-acting steam-hammers, superseding the noisy and destructive tappet action then in use by one approaching more nearly to the gliding motion of an eccentric; a number of steam-hammers have been made on this plan, for which he received a medal at the Paris Exhibition of 1867. He also designed the wrought-iron wheel for traction engines, in place of the old wooden wheel with metal tire; and the frame-slotting machine now universally used. In 1862 he commenced business at the Goodman Street Works, Hunslet, Leeds, which are now among the largest in the world for the construction of hydraulic machinery and of machinery used in the manufacture of iron and steel. As early as 1863 he proposed a hydraulic forging press for a Sheffield firm, to be used instead of a steam-hammer; and although the plan was not carried out at that time, more recently, since the masses of steel to be dealt with have gradually become so great, the superiority of the press over the hammer has become recognised, not only for working the steel into form, but also for pressing it to the very core, and making it denser, tougher, and stronger. His firm have made forging presses for all the European governments, and for many of the largest works in this and other countries. He made the first hydraulic press for bending armour-plates, and has since supplied these presses to the largest works in the world. With improvements in Bessemer machinery he was early associated; and on the introduction of the basic process he made the first converters and hydraulic machinery. In the rolling of weldless tires and in reversing apparatus for rolling mills, he introduced various improvements. He early proposed making Bessemer blowing engines compound, with the result of a saving of 30 per cent.; and the first compound reversing rolling-mill engines were made by his firm. He introduced the separate condensation engine for taking the exhaust steam from one or more engines; and also the three-cylinder blowing engine for cupolas and smiths' fires, which owing

to its great economy and efficiency has to a large extent replaced fans and other blowers. Among the many improvements he effected in hydraulic cranes, the most notable is the double-ram ingot crane for economising water. The original ingot cranes were plain centre-ram cranes with the water acting on the bottom of the ram; or else the ram was made of two different diameters, and the water pressing on the annular area raised the jib and the load. This arrangement was wasteful in pressure water, as it necessitated power to lift not only the load but also the dead weight of the jib. He therefore employed the centre ram as a guide and to take the strain only; and introduced two side rams, one in constant communication with the accumulator, nearly balancing the dead weight, and the other under control of the workman by means of a valve. Cranes on this double-ram plan have been supplied to nearly all the large steel works and arsenals. His latest achievement was the combined vertical and horizontal press for forging steel slabs and ingots by hydraulic power. Increase in the pressure of steam, and in the sizes and speeds of ships, called for larger and thicker plates, which necessitated much larger ingots and a higher quality of steel. He early recognised the importance of working the plate ingot on the edge as well as on the flat; and in the horizontal and vertical forging press plate-ingots of any size can be squeezed both horizontally and vertically, the ends cut off, and the slab cut into pieces, with practically no hand labour, the quality of steel being improved and the waste greatly diminished. In 1885 he was a member of the jury of the International Inventions Exhibition. In 1887 he was made a magistrate of the borough of Leeds. His death took place on 14th April 1891 at his residence, Moor Allerton Hall, Leeds, from inflammation of the lungs, brought about by a severe cold, in the seventieth year of his age. He became a Member of this Institution in 1867, and was a Member of Council from 1885. He was a frequent attendant at the Meetings, and often took part in the discussions. He was also a Member of the Institution of Civil Engineers, and a Member of Council of the Iron and Steel Institute.

Trial of the "Iona."

Fig. 1. *Total Coal, Water, and Revolutions; and Temperatures of Chimney Gases and of Feed-Water.*



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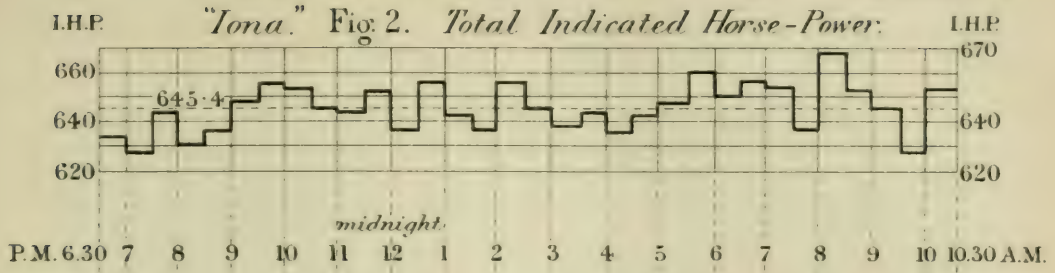
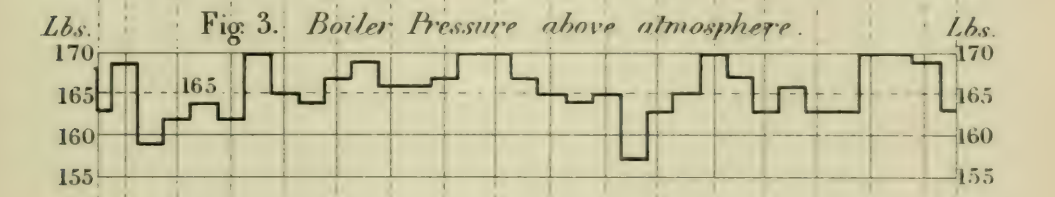
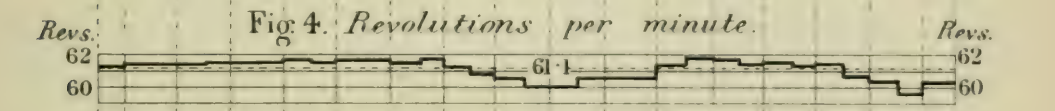
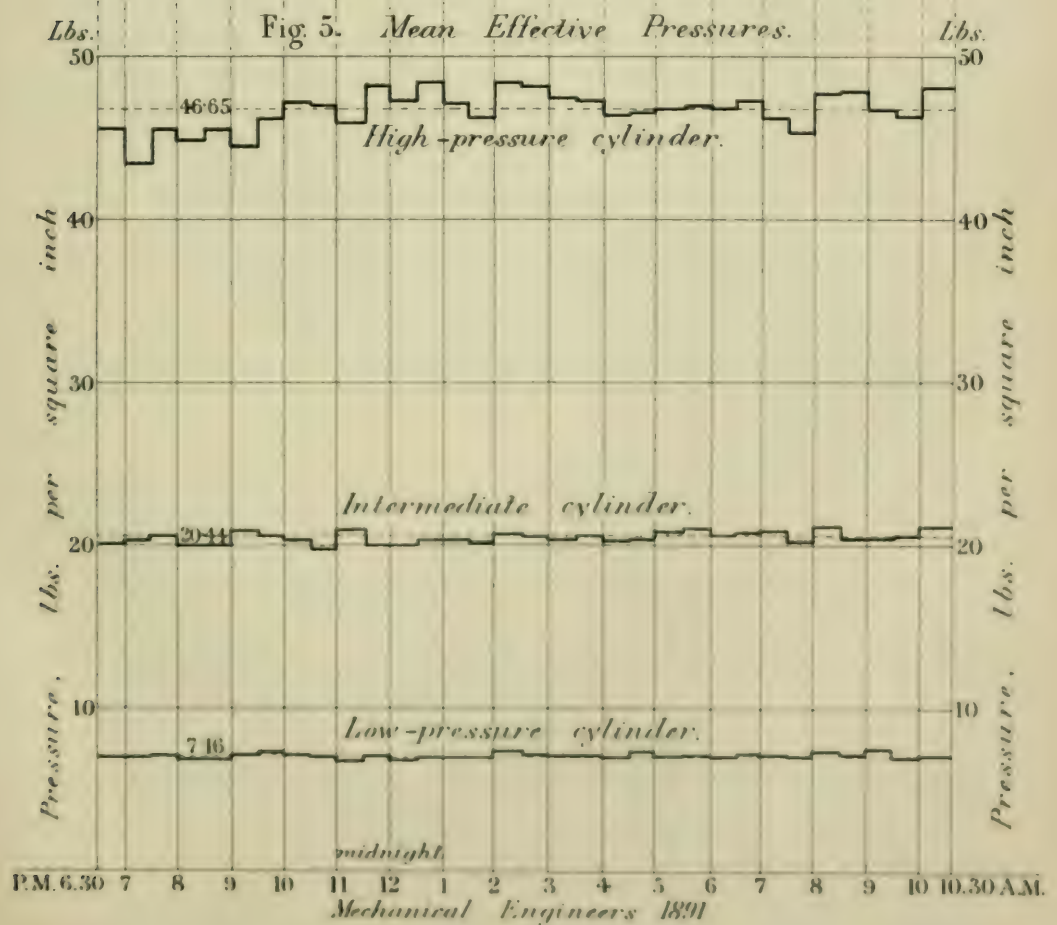

I.H.P.
"Iona." Fig. 2. Total Indicated Horse-Power.
I.H.P.
660
640
620
645·4
670
640
620
midnight.
P.M. 6.30 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 10.30 A.M.


Lbs.
Fig. 3. Boiler Pressure above atmosphere.
Lbs.
170
165
160
155
165
170
165
160
155


Revs.
Fig. 4. Revolutions per minute.
Revs.
62
60
61·1
62
60


Lbs.
Fig. 5. Mean Effective Pressures.
Lbs.
50
46·65
High-pressure cylinder.
40
30
Intermediate cylinder.
20·44
20
10
7·16
Low-pressure cylinder.
Pressure, lbs. per square inch
midnight.
P.M. 6.30 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 10.30 A.M.

"Iona" Indicator Diagrams, Set 9.

Boiler Pressure 165 *lbs*

Fig. 6. *High-pressure cylinder.* *Revs.* 61·5 *per min.* *Total* I.H.P. 645·8. I.H.P. 208·0.

Mean Pressures, Top end 47·92 *lbs., Bottom* 45·90 *lbs.*

Bottom end *Top end*

Lbs. inch above atmosphere — *Lbs. inch above atmosphere*

Fig. 7. *Intermediate cylinder.* I.H.P. 217·4.

Mean Pressures, Top end 19·42 *lbs., Bottom* 20·52 *lbs.*

Bottom end *Top end*

Pressure, lbs. per square inch

ATM. LINE

Fig. 8. *Low-pressure cylinder.* I.H.P. 220·4.

ATM. LINE

Mean Pressures, Top end 6·85 *lbs., Bottom* 7·50 *lbs.*

Bottom end *Top end*

Mechanical Engineers 1891 *Percentage of Stroke*

14·58

Trial of the "Iona."

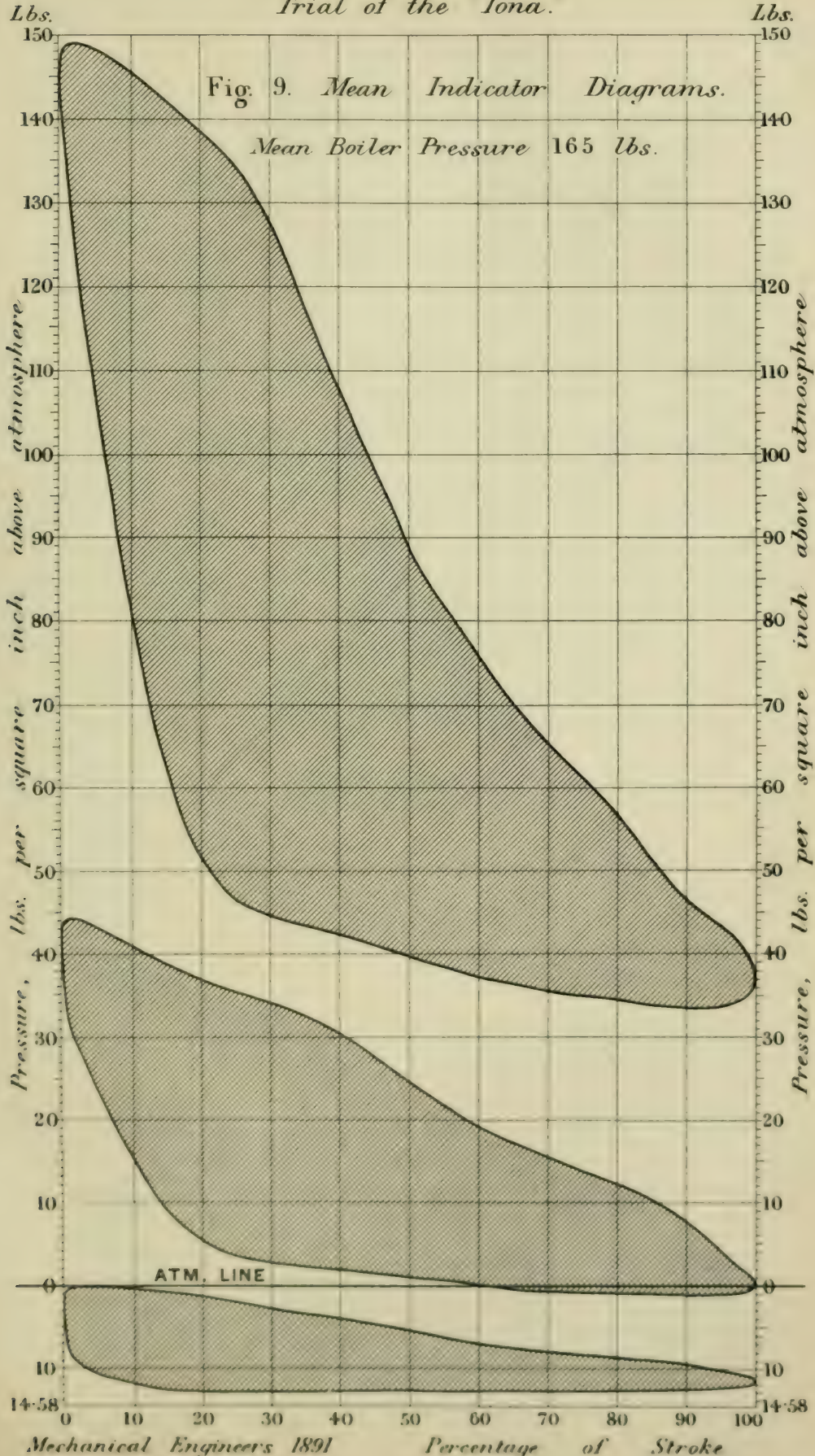


Fig. 9. *Mean Indicator Diagrams.*

Mean Boiler Pressure 165 lbs.

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Trial of the "Iona."

Indicator Diagrams from Receivers, and Air and Circulating Pumps.

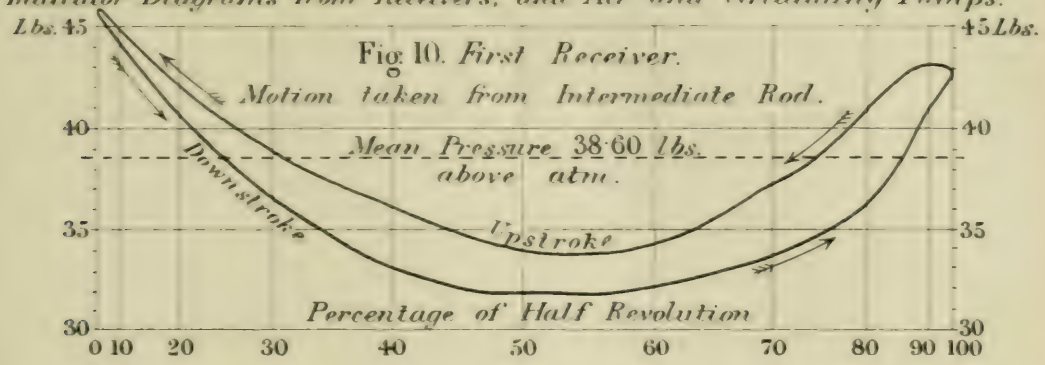


Fig. 11. *Second Receiver. Motion taken from High-pressure Rod.*

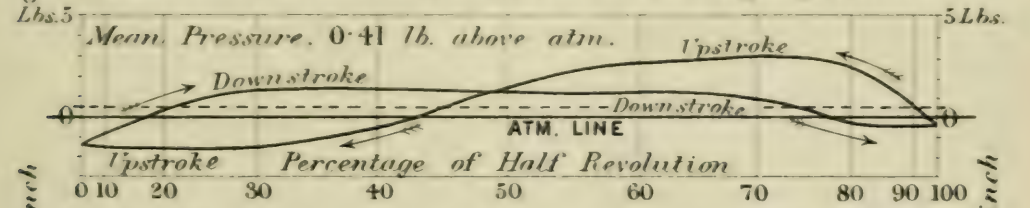
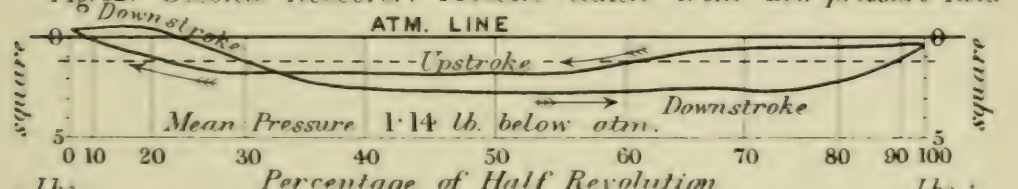


Fig. 12. *Second Receiver. Motion taken from Low-pressure Rod.*



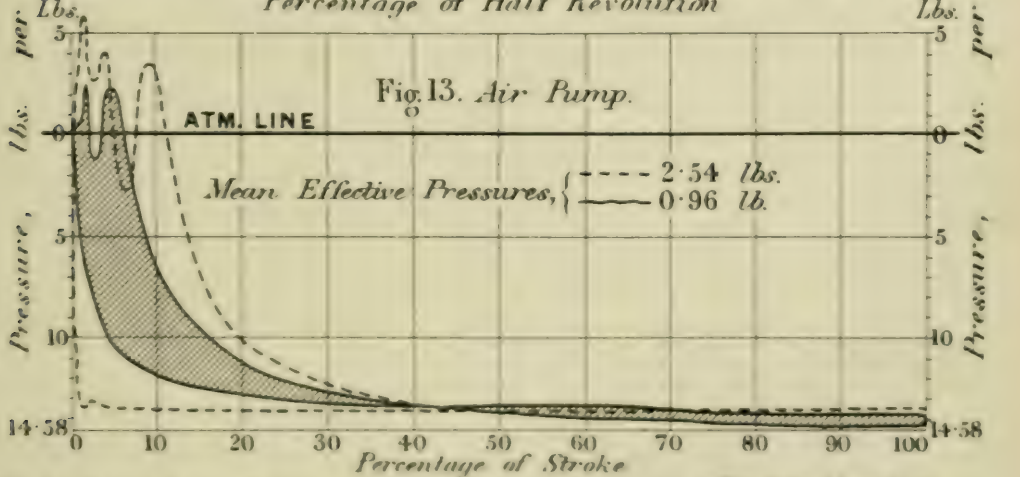
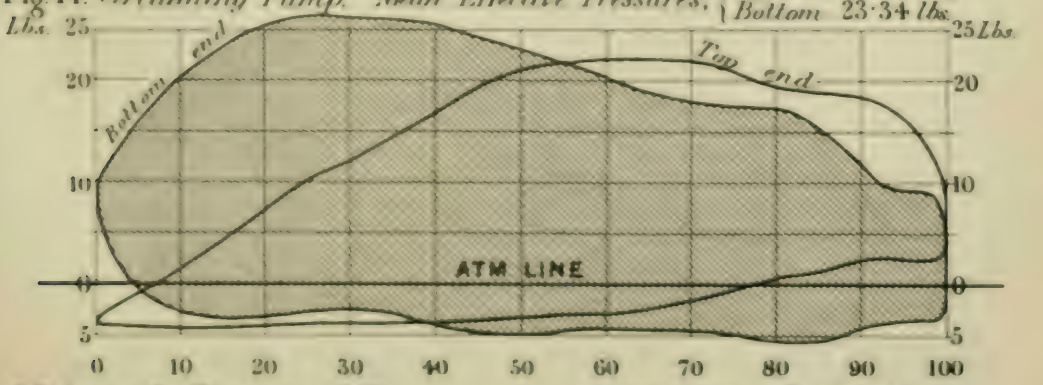


Fig. 14. *Circulating Pump. Mean Effective Pressures,* { *Top end* 16·89 *lbs.*, *Bottom* 23·34 *lbs.*



MARINE-ENGINE TRIALS. *Plate 49.*

"Iona" Subsequent Trial. Total Indicated Horse-Power.

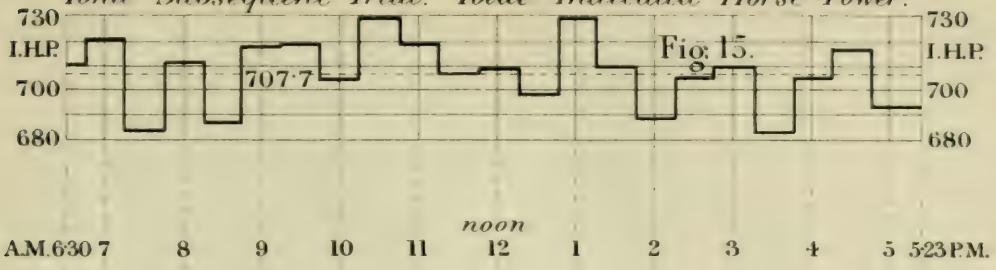


Fig. 15.

Fig. 16. *Boiler Pressure above atmosphere.*

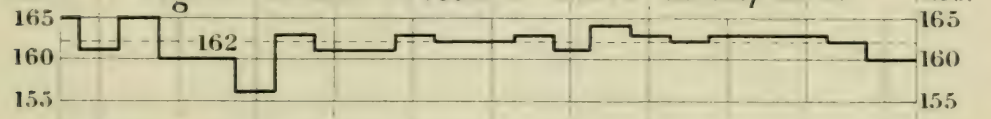


Fig. 17. *Revolutions per minute.*

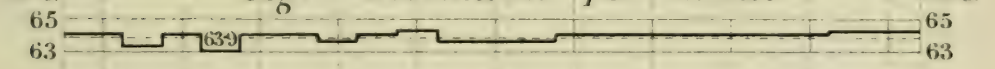
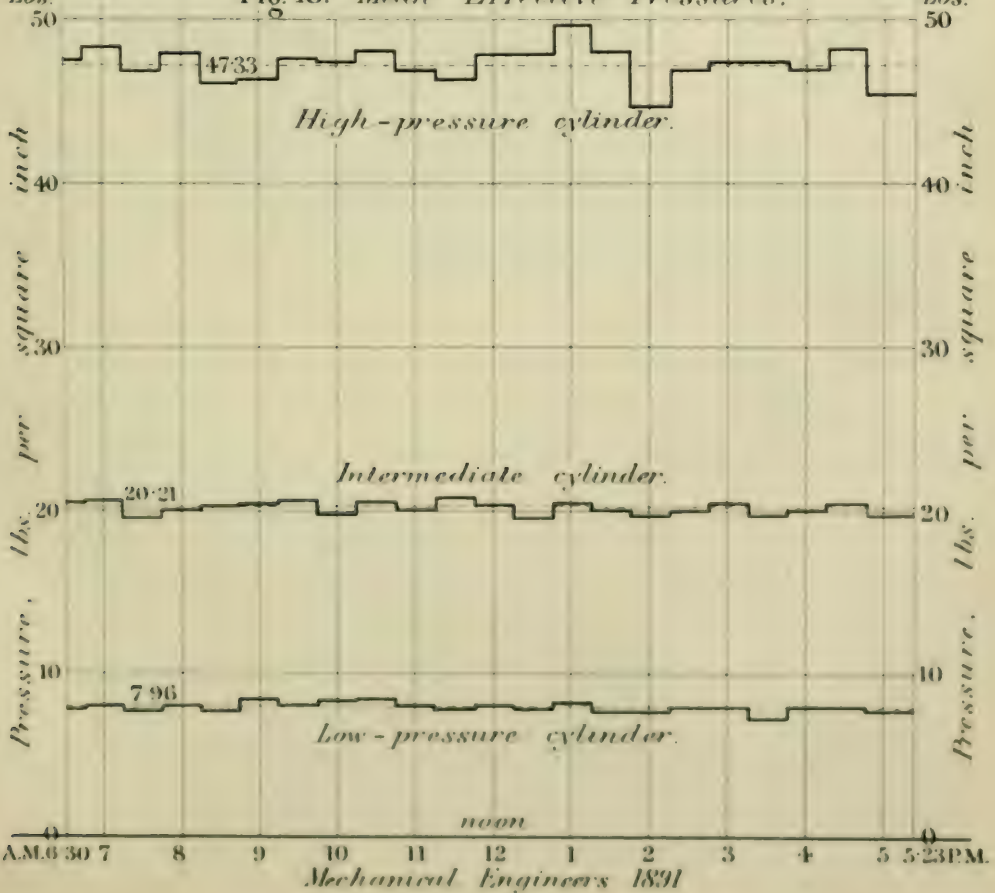


Fig. 18. *Mean Effective Pressures.*



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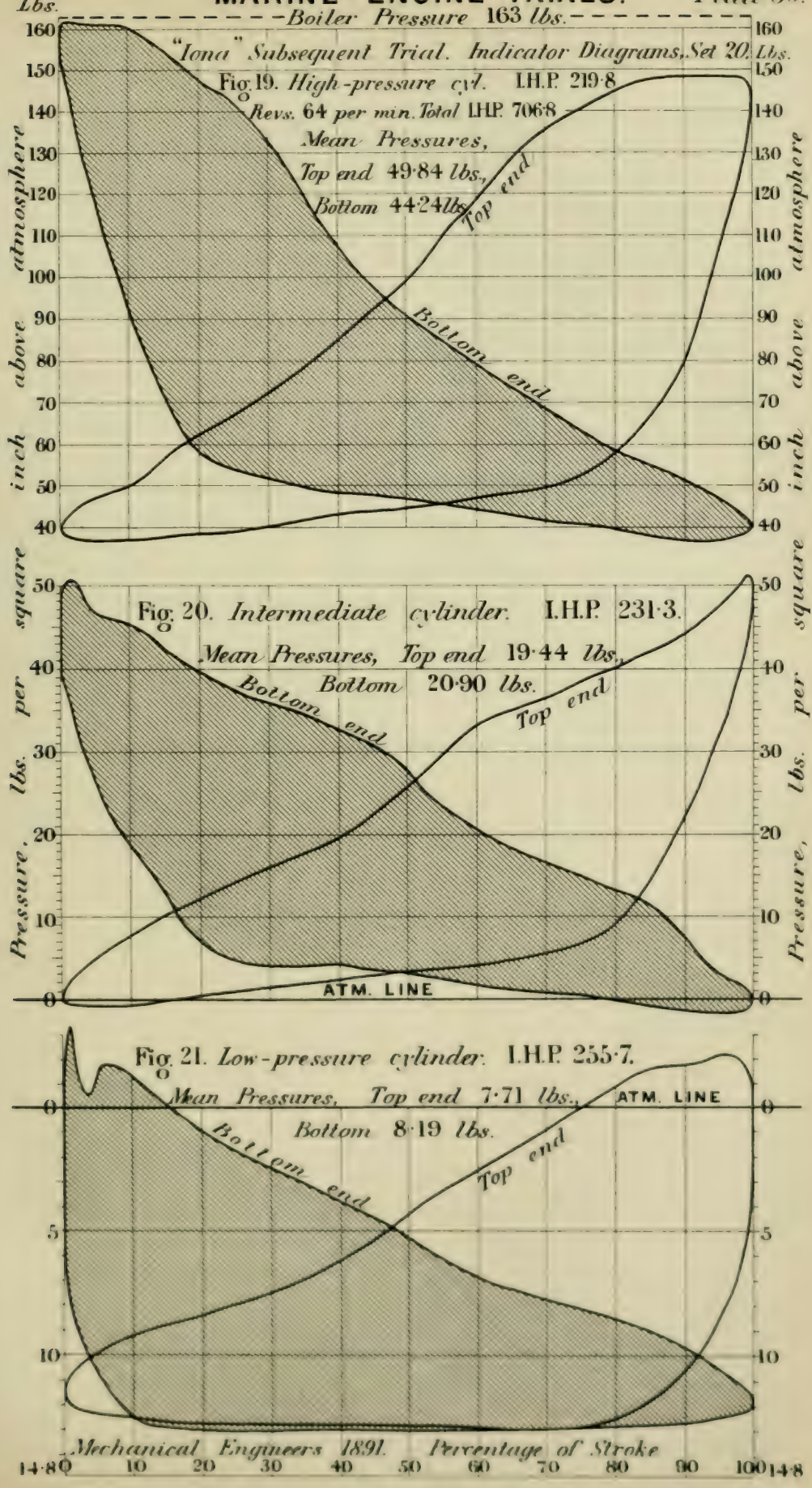
MARINE-ENGINE TRIALS.

Plate 50.



Trial of the "Iona."

Fig. 22. *Supplementary Feed - Water.*

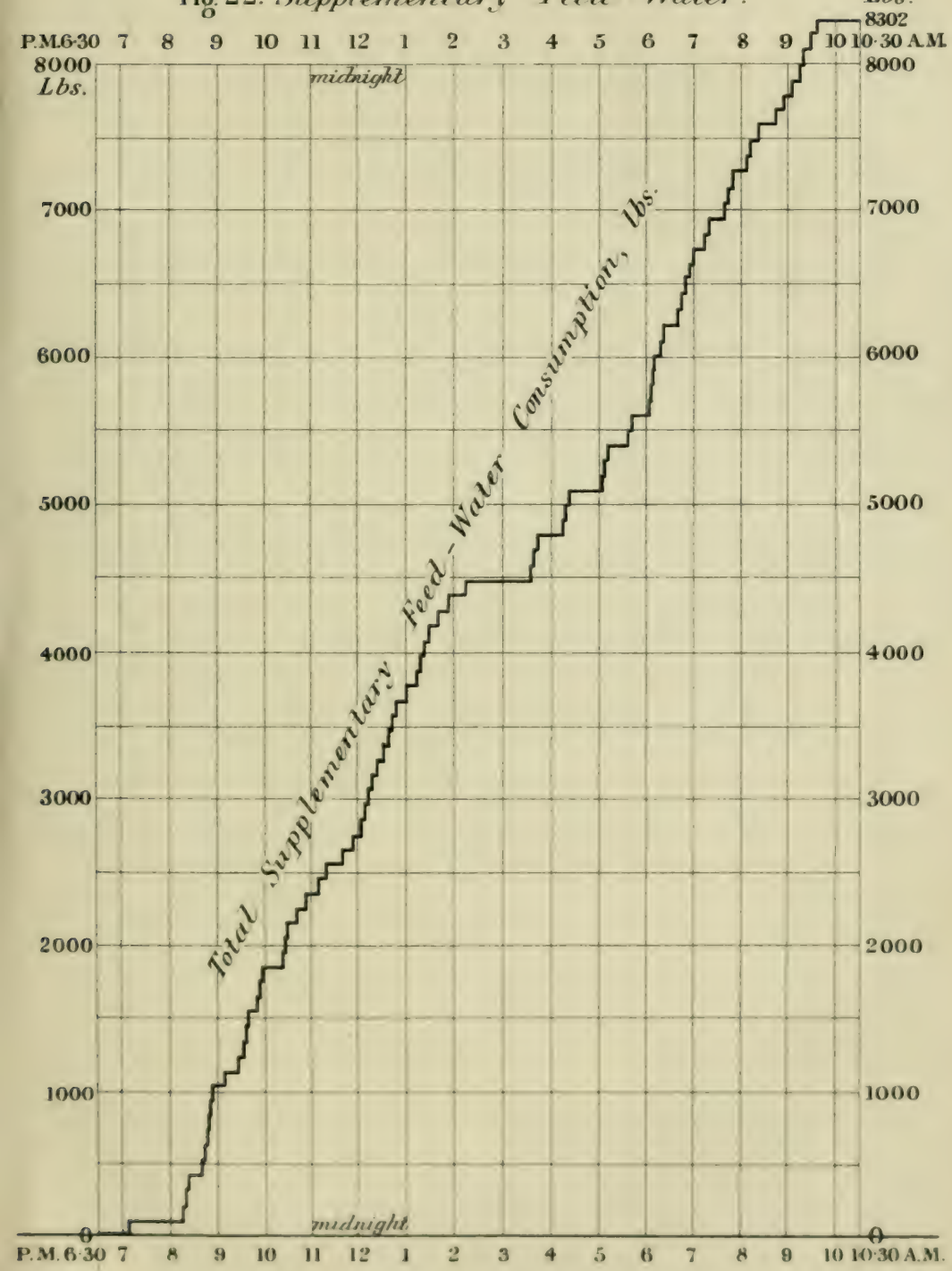
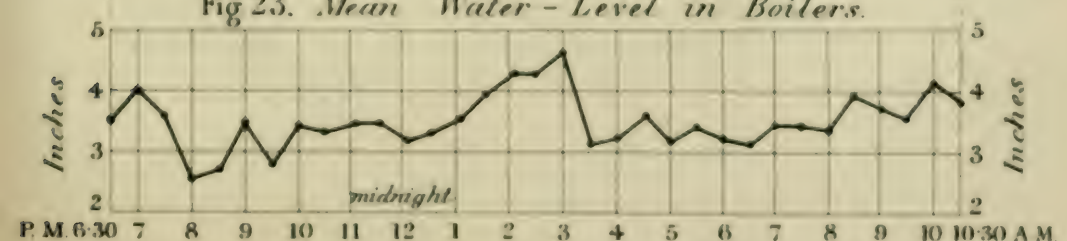


Fig. 23. *Mean Water - Level in Boilers.*



"Iona." Supplementary Feed-Water.

Fig. 24. *Nine Days' observation.*

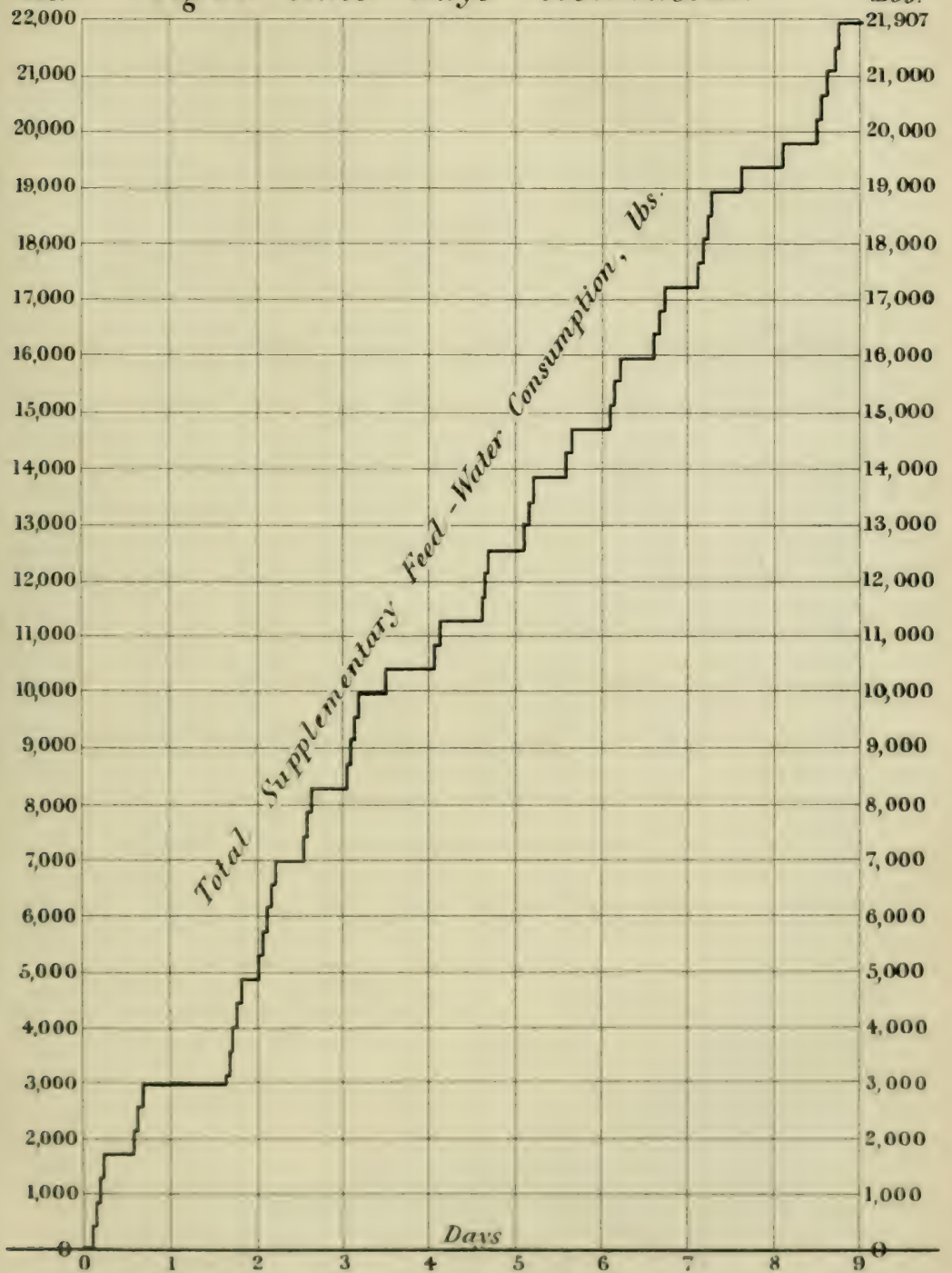
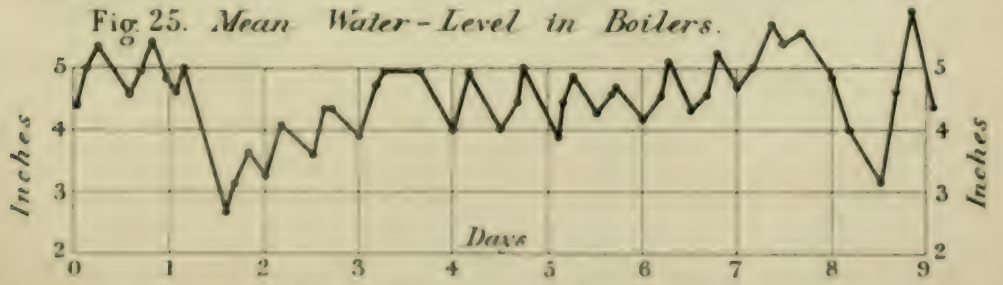


Fig. 25. *Mean Water-Level in Boilers.*

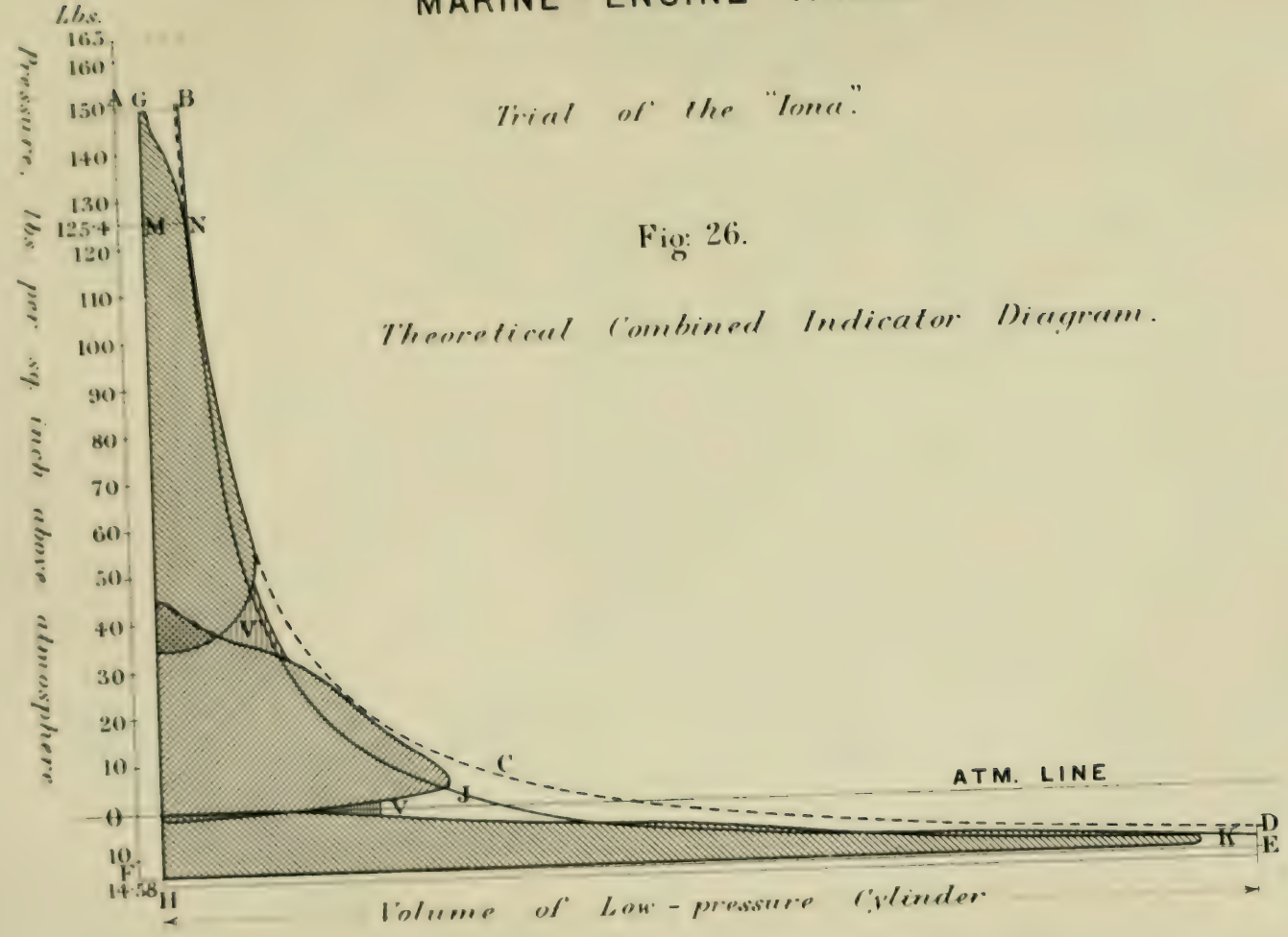


MARINE-ENGINE TRIALS.

Trial of the "Iona."

Fig. 26.

Theoretical Combined Indicator Diagram.



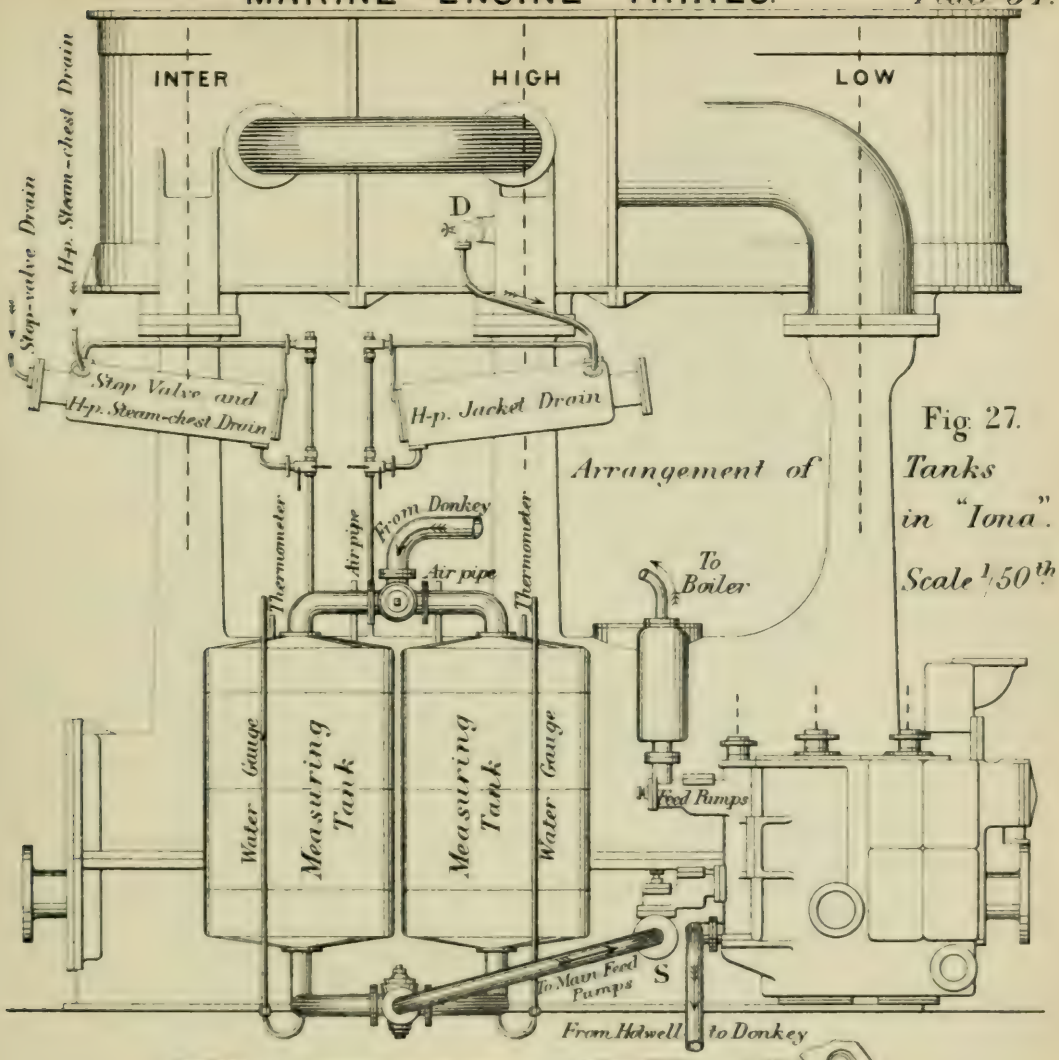


Fig. 27. *Arrangement of Tanks in "Iona".* Scale 1/50th

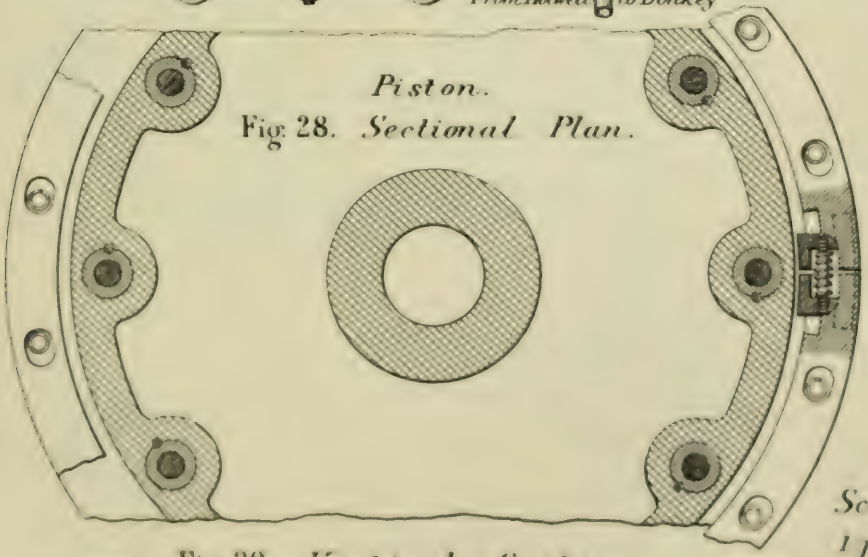


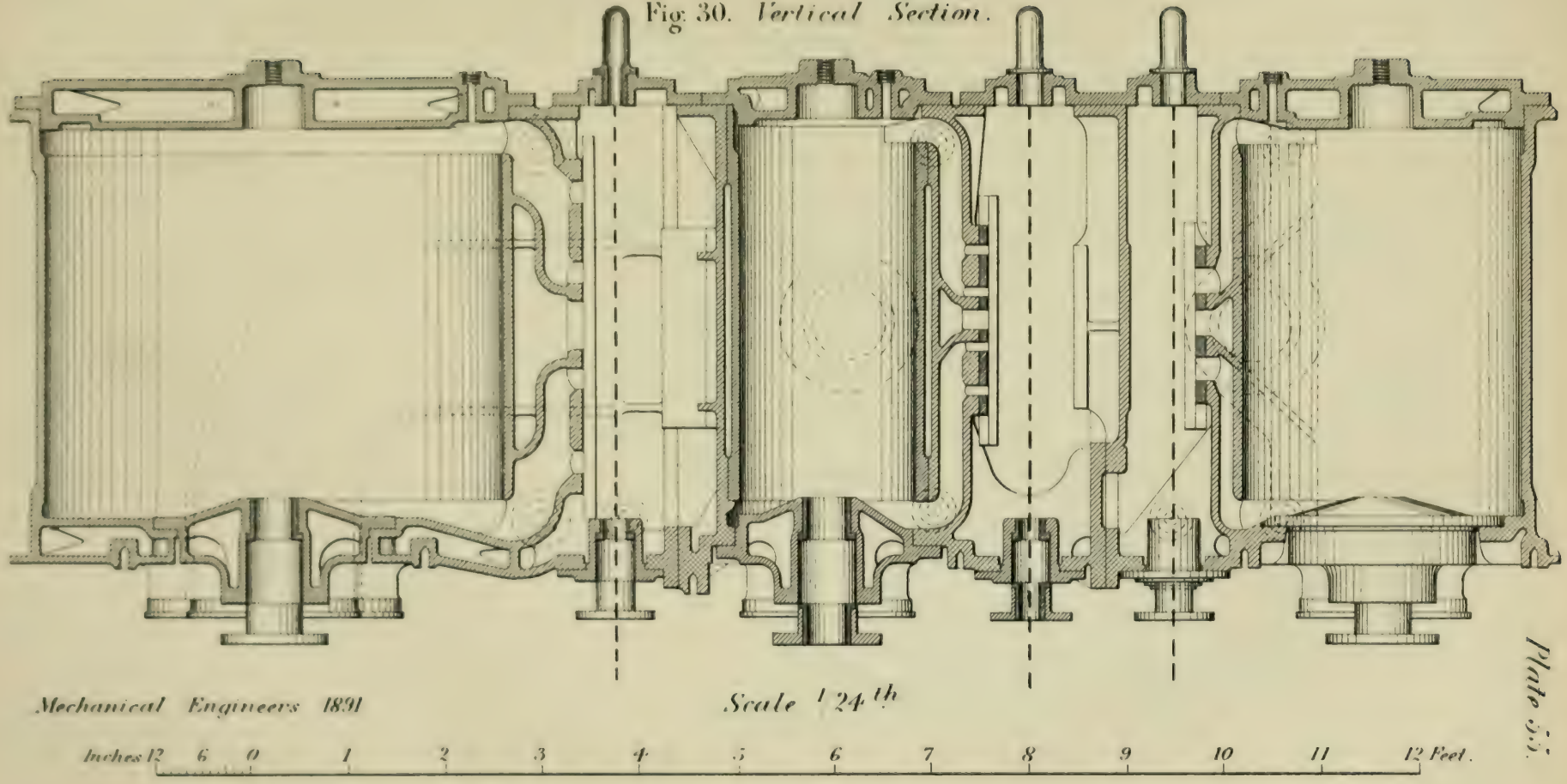
Fig. 28. *Sectional Plan.*

Scale 1/10th

Fig 29. *Vertical Section.*

Cylinders of the "Iona."

Fig. 30. *Vertical Section.*



Mechanical Engineers 1891

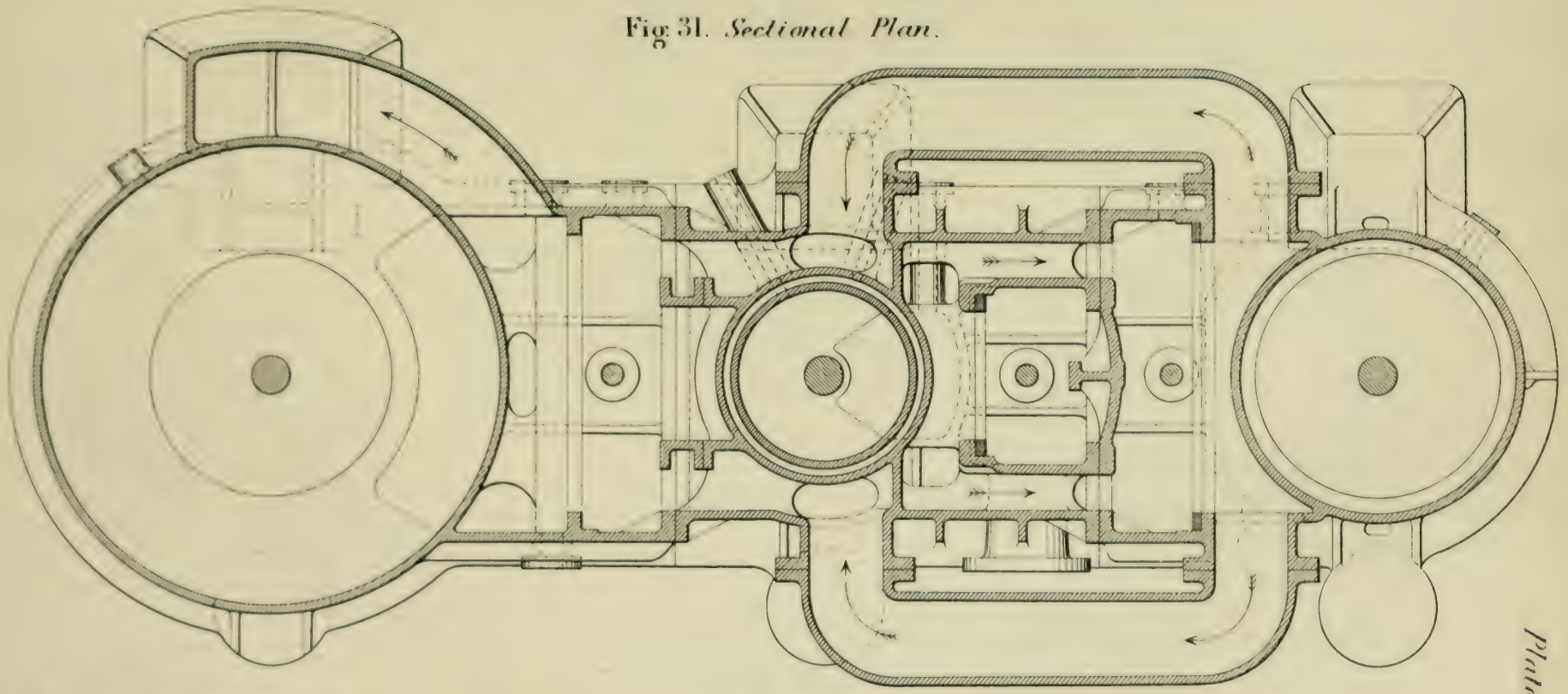
Scale 1/24th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

Plate 55.

Cylinders of the "Iona."

Fig 31. *Sectional Plan.*



Mechanical Engineers 1891 *Scale 1/24th*

inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

Plate 56.

Forced Draught Arrangement in the "Iona."

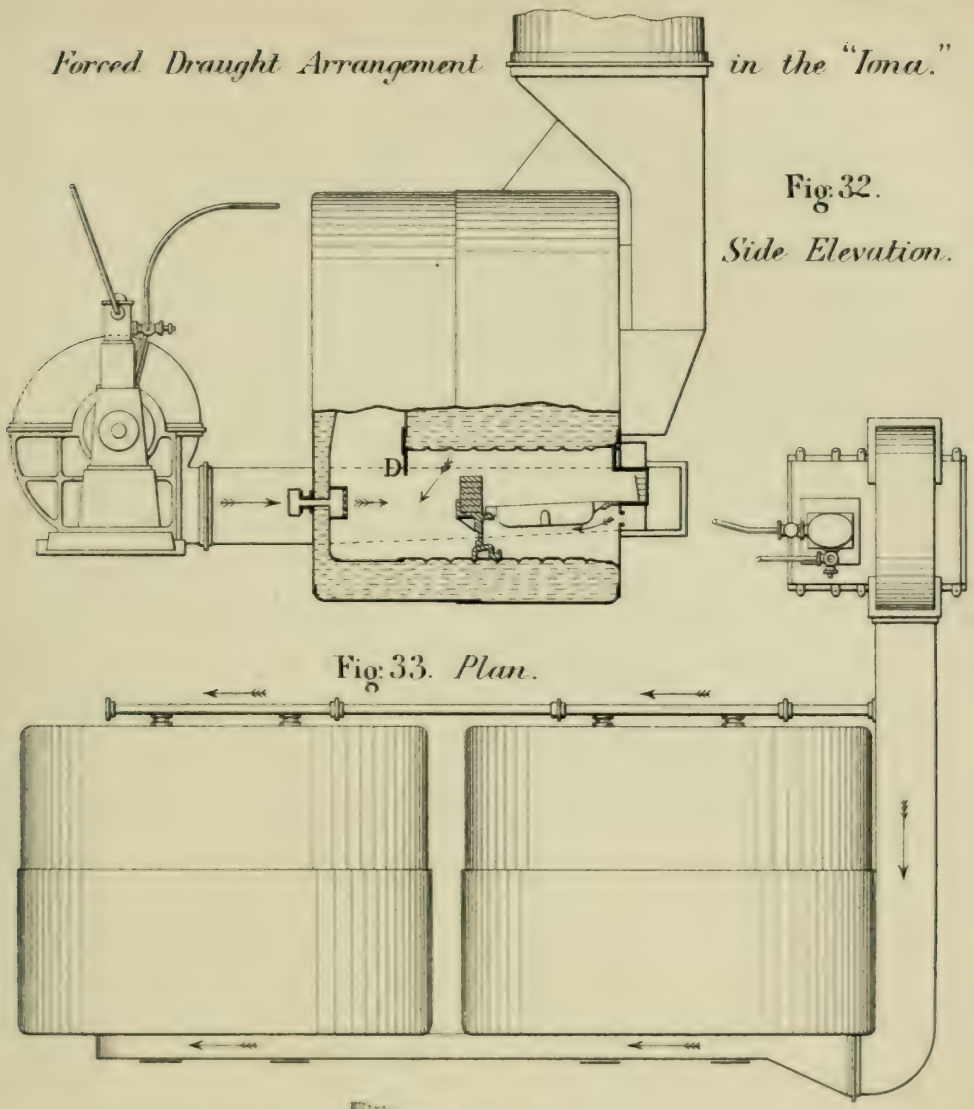


Fig. 32.
Side Elevation.

Fig. 33. *Plan.*

Fig. 34.
Front Elevation.

Mechanical Engineers 1891 *Scale $\frac{1}{96}$th*

0 5 10 15 20 25 Feet 30

Boilers of the "Iona."

Fig. 35. *Longitudinal Section.*

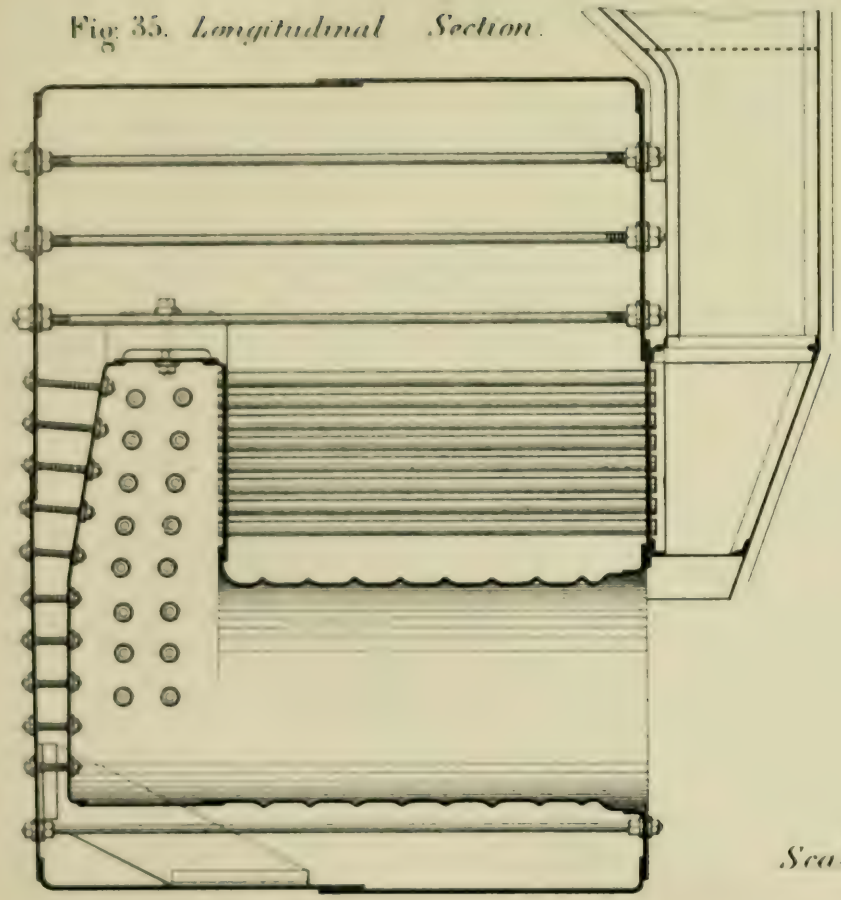
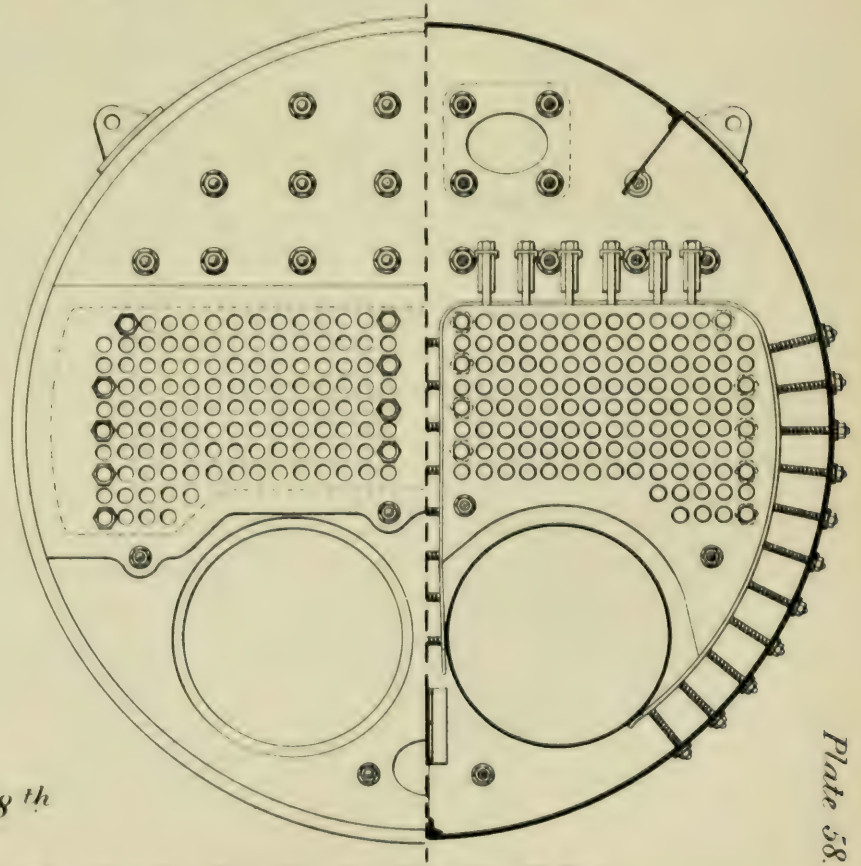


Fig. 36. *End Elevation and Transverse Section.*



Scale $\frac{1}{48}^{th}$

Inches 12 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

Mechanical Engineers 1891

Plate 58.

Calorimeter.

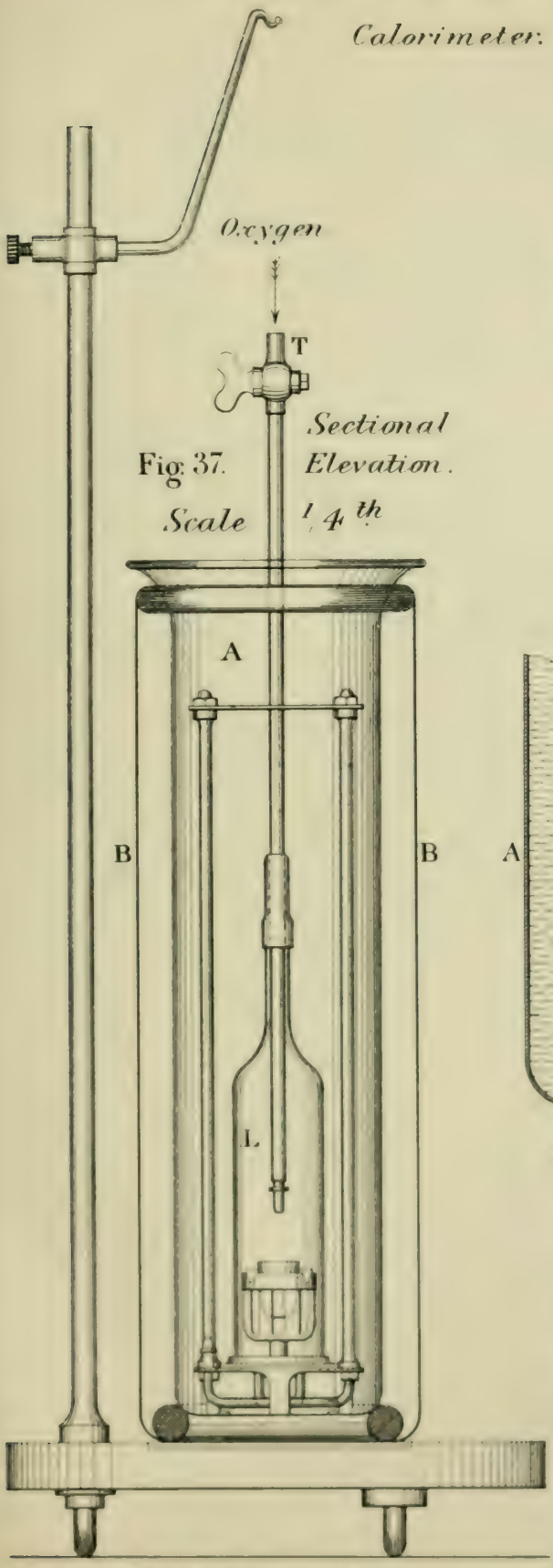


Fig. 37. *Sectional Elevation.*
Scale 1/4th

Fig. 38. *Plan.*

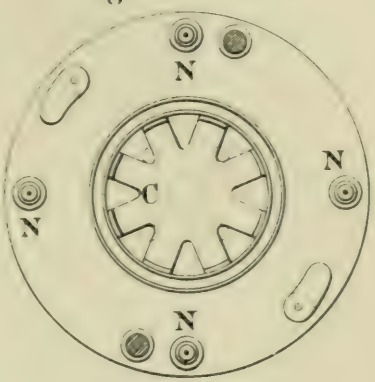


Fig. 39. *Vertical Section.*

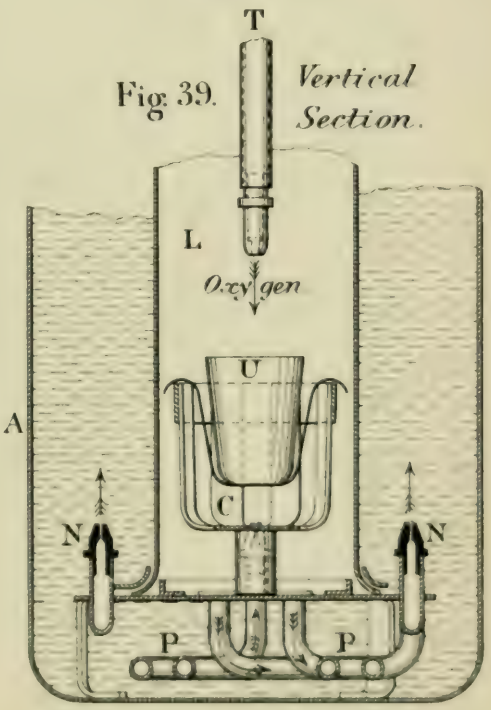


Fig. 40. *Inverted Plan.*

Scale half size.

Institution of Mechanical Engineers.

PROCEEDINGS.

July 1891.

The Summer Meeting of the Institution was held in Liverpool, commencing on Tuesday, 28th July 1891, at Ten o'clock a.m.; Joseph Tomlinson, Esq., President, in the chair.

The President and Council and Members were received in the Concert Room of St. George's Hall, by the Mayor, Joseph B. Morgan, Esq., and other members of the Reception Committee.

The Mayor said that, both as Mayor of Liverpool, and also as himself an Associate of the Institution of Mechanical Engineers, he desired to give the Members a hearty welcome to the city, not only in the name of the Reception Committee of which he was the Chairman, but also on behalf of the citizens generally. During his year of office it was very pleasing to him to have this opportunity of welcoming here an old friend of his own as the President of the Institution. With Mr. Tomlinson he had worked for a long period in the pursuit of the same object; and he had learned to appreciate highly the sound and practical way in which he was in the habit of dealing with engineering matters. It was a great gratification to him to have Mr. Tomlinson as his guest on the present occasion. Nineteen years had now elapsed since the city of Liverpool had last been honoured with a visit from the Institution. The Members who had been present on the former occasion he hoped would discover in their present visit that the city had not been behindhand in mechanical engineering and in carrying out other important works. He trusted that the works which the Members would see on the present occasion would meet with their approval, and would show that the city had advanced in the same degree as other large cities in the United

(The Mayor.)

Kingdom. The construction of the Vyrnwy Water Works, though now approaching completion, was not yet actually finished; that was an undertaking of which, in so far as it was advanced towards completion, Liverpool was rightly proud. Amongst the Council of the Institution who were present he was glad to see many well-known engineers who were specially welcome to Liverpool, holding as they did high positions under the Government of the country, and in various engineering establishments. He took credit on behalf of Liverpool for the fact that, when the Government had asked for armed cruisers, out of the seven for which tenders or plans were sent in for adoption four vessels were offered by Liverpool, and sailed from Liverpool; and one of the four was the first to put in an appearance at the late naval review at Spithead as an armed cruiser fully equipped. A short time ago he had enjoyed the pleasure of visiting the lighthouses round the coast, in company with those who had the charge of them. He had never visited so many lighthouses before, and he was greatly pleased with the admirable manner in which they were constructed and maintained. He was glad to see present on this occasion their Vice-President, Sir James Douglass, who, as the Engineer of Trinity House, had charge of the lighthouses round the coast. From the position that he occupied he was specially welcomed to Liverpool by the ship-owners; and the inhabitants of Liverpool were not behind the rest of the country in highly appreciating his successful efforts in superintending recently the rebuilding of the Eddystone Lighthouse. As a native of Liverpool, the Members would not be surprised that he naturally thought Liverpool the finest city in the world; it would be strange if he did not, and he was proud of it for various reasons. Besides what he had already mentioned with regard to the armed cruisers, he was also proud to think that Messrs. Laird were now building one of the largest line-of-battle ships, if not the very largest, the "Royal Oak," of 14,000 tons; their works, though situated in Birkenhead, were on ground rented from the Corporation of Liverpool, so that he was glad to claim them as belonging entirely to Liverpool. On their visit to those important works he had no doubt the Members would inspect with great interest the vast operations involved in the

construction of that large vessel. He was particularly pleased to see that their Member of Council, Mr. W. H. White, Assistant-Controller and Director of Naval Construction, was also present to receive the hearty welcome which Liverpool had to offer him. All the plans connected not only with the "Royal Oak" but also with the armed cruisers had undergone his examination and approval; and from the position which he held in the Admiralty his visit was most acceptable to Liverpool. The Members having assembled for business, he would conclude by offering them a formal welcome, which he did in all sincerity and heartiness. He hoped to have the pleasure of entertaining them at the Walker Art Gallery in the evening, when they would have the opportunity of seeing the art treasures and other belongings of the Corporation. It was a satisfaction to him to inform them that everything which would there be presented to them, even including the music, pertained directly to Liverpool.

The PRESIDENT said the Members of the Institution desired to join him in thanking the Mayor and his Reception Committee for all the pains they had taken to render the present visit, as it would no doubt prove, a perfect success. The Mayor had personally taken a great deal of trouble, and they sincerely thanked him for his efforts. As had already been mentioned, Mr. Morgan had been occupied for some years in London with himself in connection with the telephone; he had indeed been the chief promoter of the system, and had mainly contributed to its success. It was possible now to talk between London and Paris and between London and Edinburgh, as well as between London and Liverpool and Manchester; and he could truly say that they were mainly indebted to Mr. Morgan's energies for the attainment of this result. He desired to tender to the Mayor the sincere thanks of the Members for what had been done on their behalf; and he hoped to do so again later on when they had seen more of what he had done for them.

The MAYOR replied that he himself hardly deserved the thanks which had been offered him. The Executive Committee however

(The Mayor.)

had certainly done their work with remarkable energy; and there were two gentlemen especially to whom he thought the thanks of the Members were chiefly due, namely Mr. West and Mr. Daglish. Mr. West's untiring energy as Honorary Secretary had been something unparalleled. Though he had come in contact with many gentlemen, and had been connected with the organisation of various societies and works of construction, he had never come across any one who had worked so much in harmony with himself, and so indefatigably, as Mr. West. They were also greatly indebted to Mr. Daglish for the very active part he had taken as Honorary Treasurer. He could only say that, if it should be his good fortune to be connected with any similar work on any future occasion, nothing would give him greater pleasure than to be associated with two such gentlemen.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following fifty-four candidates were found to be duly elected:—

MEMBERS.

WILLIAM ANDERSON,	Stockton-on-Tees.
HENRY ASHWORTH,	Erith.
HAZLITT MICHAEL BEATTY,	Cape Town.
FRANCIS EDWARD BEST,	London.
GEORGE BIRD,	London.
ARTHUR HENRY BLACKBURN,	London.
ARTHUR MAUDSLAY BROTHERHOOD,	London.
ARTHUR MOGG BROWN,	Johannesburg.
FRANCIS CHASSEREAU BOUGHEY BURGESS,	Bezwada, India.
AUGUSTUS CLARK,	Pernambuco.
JOHN HUBERT DAVIES,	Johannesburg.
CHARLES RILEY GARRARD,	Birmingham.
RICHARD ALFRED GROOM,	Wellington, Salop.

Otto Simon Henry Harcourt,	Leeds.
George William Hawksley,	Sheffield.
Thomas Henderson,	Liverpool.
Frank Grattidge Hodges,	Derby.
Hugh Wilson Holman,	London.
Robert M. Hughes,	Liverpool.
Lacey Robert Johnson,	Vancouver.
Andrew Johnston,	Hong Kong.
Edward Manisty,	Dundalk.
Edward Charles Robert Marks,	Birmingham.
Arthur Latimer McCredie,	Sydney.
George McFarlane,	Glasgow.
Thomas de Courcy Meade,	London.
William Charles Melville,	Liverpool.
Robert Macmillan Murdoch,	London.
George North,	London.
Robert J. Paton,	Campinas, Brazil.
Matthew Paul, Jun.,	Dumbarton.
Henry Handley Pridham Powles,	London.
Hugh Reid,	Glasgow.
Henry John Scott,	London.
Robert Julian Scott,	Christchurch, N.Z.
James Shenton,	Hyde.
Russell Sinclair,	Sydney.
John Reney Smith,	Liverpool.
William Spencer,	Manchester.
James Stevens,	London.
James Thompson,	Wolverhampton.
Tom Westgarth,	Middlesbrough.
John Whittaker,	Oldham.
Thomas Wylde,	Johannesburg.

ASSOCIATES.

James Porteus Cornett,	Sunderland.
Joseph Jackman,	Sheffield.
Adam McMeekin,	Doagh.
John Barbour Pirrie,	Carrickfergus.

GRADUATES.

CHARLES HENRY CASWELL, . . .	Cardiff.
SAMUEL CUTLER, JUN., ...	London.
ALFRED EDWARDS DOUGLASS, . .	London.
HERBERT FRANCIS EDWARDS, . .	Cardiff.
HENRY HODGES MOGG GREGORY, . .	London.
JOSEPH PHILIP GRACE SMITH, . .	London.

The following Paper was then read and discussed :—

"A Review of Marine Engineering during the past decade"; by Mr. ALFRED BLECHYNDEN, of Barrow-in-Furness.

Shortly after One o'clock the Meeting was adjourned to the following morning.

The ADJOURNED MEETING was held in the Concert Room of St. George's Hall, Liverpool, on Wednesday, 29th July 1891, at Ten o'clock a.m.; JOSEPH TOMLINSON, Esq., President, in the chair.

The following Papers were read and discussed :—

"Description of the Warehouse and Machinery for the Storage and Transit of Grain at the Alexandra Dock, Liverpool"; by Mr. WILLIAM SHAPTON, of London.

"On the Experimental Marine Engine and the Alternative-Centre Testing Machine in the Walker Engineering Laboratories of University College, Liverpool"; by Professor H. S. HELE-SHAW, of Liverpool.

"On the Mechanical Appliances employed in the construction of the Manchester Ship Canal;" by Mr. E. LEADER WILLIAMS, Engineer in Chief.

The remaining Paper announced for reading and discussion was adjourned to a subsequent meeting.

The PRESIDENT proposed the following Votes of Thanks, which were passed with applause :—

To the Mayor of Liverpool, Joseph B. Morgan, Esq., for his personal hospitalities, and for his kindness in obtaining the grant of the accommodation of St. George's Hall for holding the Meeting of this Institution.

To the Reception Committee—and especially to the Mayor as Chairman, Mr. Thomas B. Royden, M.P., as Vice-Chairman, the Honorary Treasurer Mr. Geo. Heaton Daglish, and the Honorary Secretary Mr. Henry H. West—for the admirable arrangements they have made for welcoming the Institution so hospitably in Liverpool, and for the convenience and enjoyment of the Excursions they have so obligingly planned for the Members.

To the Owners of the R.M.S. "Majestic," the Directors of the Liverpool Grain Storage and Transit Company, the Directors and Engineers of the Liverpool Overhead Railway, the Council and Senate of University College, the Mersey Docks and Harbour Board, the Directors of the Mersey Tunnel Railway, Messrs. Laird Brothers, the Directors of the Lancashire and Yorkshire Railway, the Directors of the Manchester Ship Canal, and the rest of the Proprietors through whose kind invitations the Members have been enabled to enjoy the advantage of visiting the numerous Engineering Works and other Establishments opened to their inspection during the Meeting.

To the Directors of the London & North Western and the Lancashire & Yorkshire Railways, for their kindness in offering special facilities for the Excursions over their lines.

The PRESIDENT said that, when it was contemplated that the Institution should re-visit Liverpool this summer, as soon as he heard that Mr. Morgan was to be Mayor he went to see him, and expressed a hope that the Mayor would do his best to assist the object in view. He readily and cordially assented; and the Members had now witnessed how admirably he had fulfilled his

(The President.)

promise. They had received his hospitality at yesterday evening's entertainment; and this evening he would receive theirs at the Institution Dinner, at which he hoped that as many of the Members as possible would attend, so as to be able to accord to him then a further expression of gratitude for all he had done.

The MAYOR OF LIVERPOOL said he was very glad to have had the opportunity of offering hospitality to their President as a personal friend, and with equal heartiness to his other friends among the Mechanical Engineers. As to his entertainment of the Members at yesterday evening's "At Home," the great reward to himself was to find that they had all enjoyed it. He hoped that what the Members had seen of Liverpool had pleased them, and that they did not regard this city as "the dark spot by the Mersey." He was proud of the city, and felt sure from what he had heard from those who had attended the present meeting that its advance in mechanical improvement and in other ways had been noticed by them as something remarkable. He was glad to say that everything they had seen on the previous evening belonged to Liverpool: the pictures and books; the gold and silver, some of which had been used in the Town Hall for more than two centuries; the pottery, with its magnificent colouring, the art of which had been lost—some of it made on the site of the Art Gallery in which they had then been assembled, and some made at the Herculaneum Works, the site of which was now occupied by docks, in consequence of the great progress that had taken place in dock extension. All the things he had mentioned were the property of the citizens of Liverpool, who were always proud to show their art treasures, and to welcome all who appreciated them. During his year of office this meeting of the Institution would form a red-letter day, which he could assure the Members he should always remember with great pleasure, as he hoped they would do also.

The PRESIDENT said that, in connection with the vote of thanks which had been passed to the Reception Committee, he wished especially to draw attention to the exertions of the Honorary

Treasurer, Mr. Daglish, and the Honorary Secretary, Mr. West. With regard to Mr. West, he knew that he had worked indefatigably for the Institution at the sacrifice of his own personal business; he had done everything in his power to ensure the success of this meeting in Liverpool, and its success was largely attributable to his untiring exertions.

The vote of thanks was acknowledged by Mr. DAGLISH and Mr. WEST.

The Meeting then terminated shortly after One o'clock. The attendance was 305 Members and 67 Visitors.

A REVIEW OF MARINE ENGINEERING DURING THE PAST DECADE.

By Mr. ALFRED BLECHYNDEN, of Barrow-in-Furness.

The Institution has previously had two papers dealing with the progress of Marine Engineering:—that by Sir Frederick Bramwell, read at the meeting in this city in 1872; and that by Mr. Francis C. Marshall in 1881. The writer purposes now to review briefly the progress from the latter date until the present time.

The results of Mr. Marshall's investigations were that the type of engine then employed was the two-stage expansion compound; and from a series of examples of performances of such engines he found that in long sea voyages on the average the boiler pressure was 77·4 lbs. per square inch, the piston speed 467 feet per minute, the heating surface per indicated horse-power 3·917 square feet, and the consumption of coal per indicated horse-power 1·828 lbs. per hour. No mention was made by him of the three-stage expansion engine, although at that time at least two had been constructed, and had worked successfully for seven years. These were the engines of the "Propontis," with cylinders 23 inches, 41¼ inches, and 62⅛ inches diameter, by 42 inches stroke, constructed by Messrs. John Elder and Co. to the designs of Mr. A. C. Kirk; and those of the "Sexta," constructed at the Ouseburn Engine Works, Newcastle-on-Tyne, to the specification of Mr. A. C. Franklin, then of London, with cylinders of 11 inches, 17 inches, and 24 inches diameter, by 18 inches stroke, as illustrated in Figs. 1 and 2, Plate 60. Both of these engines were commenced in 1873, and tried in 1874, and were of the three-crank type usually built now.

Since 1881 the three-stage expansion engine has become the rule, and the boiler pressure has been increased to 160 lbs. and even as high as 200 lbs. per square inch. Four-stage expansion engines of various forms have also been adopted; and many changes have been made in

other respects, necessitated by increased pressure or by desire for increased economy or power. In dealing with the changes made during the last ten years, it will be best to commence with the furnace, and to proceed from the boiler to the engine.

Forced Draught.—Ten years ago the principle known as forced draught, so far as marine engineering in this country was concerned, had been practically confined to torpedo vessels, and the writer believes to three cruisers, each of about 2,850 horse-power, though it had long been employed in steamers on American waters. Since then it has become the rule in all vessels for naval service, and comparatively common in both passenger and cargo vessels. By this means it is possible considerably to augment the power obtained from a given boiler; and, so long as it is kept within certain limits, it need result in no injury to the boiler, but when pushed too far the increase is sometimes purchased at considerable cost.

There are several methods by which the principle may be practically applied. In the earlier cases in this country closed stoke-holds were adopted, the air being delivered into them by fans, at a pressure varying from about 1 inch to 3 inches of water. This arrangement certainly has the merit of keeping the stoke-holds cool, and its details are simple; but it is dirty, and where bunker doors are not well fitted, great discomfort may be caused on deck. Possibly also it is not quite so economical as the closed ashpit system; but such exact data as exist of its working indicate that with moderate air-pressure it is at least no less economical than natural draught. In America it was customary to close in the ashpits, and take the delivery tubes from the fans into them. This, though involving more ashpit fittings, is certainly advantageous so far as cleanliness is concerned; the furnaces are also not subjected to the severe strains caused by the inrush of cold air which occurs during firing with closed stoke-holds. As often fitted it has the disadvantage of making rather a hot stoke-hold, though with sufficient precautions there is no reason why the ventilation should not be made perfect by taking the air through the stoke-holds. In the earlier American experiments (*see* Isherwood's Experimental

Researches, vol. 2, trials of gunboats of "Chippewa" class, and "Fulton") the air was introduced into the ashpits by pipes at their back ends.

The principle of forced draught has also been carried out by placing a fan in the uptake, and exhausting through the furnaces. This plan has the great advantage of dispensing with the elaborate furnace fittings common to the undergrate systems; and according to the researches of Dr. Tyndall on combustion in condensed and attenuated atmospheres, it should result in a more perfect combustion, but how far this is realized in practice has not come within the writer's experience.

In regard to the economy of forced draught, an examination of Table 5 (appended) will show that while the mean consumption of coal in those steamers working under natural draught is 1·573 lbs. per indicated horse-power per hour, it is only 1·336 lbs. in those fitted with forced draught. This is equivalent to an economy of 15 per cent. Part of this economy however may be due to the other heat-saving appliances with which the latter steamers are fitted. But independently of the economy of forced draught in coal relatively to power, it is like all economies in marine engineering, simply a question of the comparative cost of carrying a given freight at a given speed: in other words, it is a question of the total expenses of carrying the freight with the help of forced draught, as against the total expenses with natural draught. It is not a mere matter of coal consumption, which is only one of the elements that go to make up the total. Assuming indeed that the consumption of coal per horse-power is not less with forced than with natural draught, then, since with forced draught it is possible to develop a given power from a smaller boiler and consequently with a smaller weight than with natural draught, here is at once a source of economy, because the difference in weight may be made up in freight. Such evidence as exists shows that not only is forced draught more economical as regards quantity of coal, but by its means such classes of coal may be used as would not without it be worth putting on board. It is in this direction perhaps that the greatest saving has followed its employment.

Thus far the following would appear to be a fair summary of the advantageous points attending the use of forced draught. First, it seems fairly well established that, if the boilers are well constructed and are provided with ample room to ensure circulation, their steaming power may without injury be increased to about 30 or 40 per cent. over that obtained on natural draught for continuous working, and may be about doubled for short runs. Secondly, such augmentation is accompanied in normal cases by an increased consumption per indicated horse-power. But thirdly, the same or even greater power being indicated, it may with moderate assistance of forced draught be developed with a smaller expenditure of fuel, the grates &c. being properly proportioned. Fourthly, forced draught enables an inferior fuel to be used. And fifthly, under certain conditions of weather, when with normal proportions of boiler it would be impossible to maintain steam for the ordinary speed with natural draught, the normal power may with forced draught be ensured. In particular cases any or all of these advantages may be a source of economy; and the first of them may render possible that which would otherwise be impracticable.

As now adopted in the navy, forced draught is purely an auxiliary intended for use under special circumstances. When a maximum power and speed are required only occasionally, or when the vessel is intended for cruising in hot climates, or under such conditions of weather as to impair the natural-draught power, in such cases it is a most important source of economy. Vessels of the cruiser type, which are required in case of necessity to develop say over 9,000 horse-power, while the usual cruising speed of about 10 or 12 knots requires only from 1,000 to 1,500 horse-power, are rendered possible at a reasonable cost by the adoption of forced draught. The recent troubles with naval machinery in vessels of the "Barracouta" class have done much to unsettle opinions in regard to this problem. But looked at calmly it becomes evident that the causes of those troubles are altogether apart from the question of forced draught pure and simple, and are rather questions of boiler design. So long as boilers were designed with ample spaces for internal circulation, ample capacity of furnace and combustion

chamber, and so proportioned that the surfaces of the furnaces and combustion chambers were sufficient to absorb a large proportion of the heat before the products of combustion reached the tubes, and above all so that the tube plates were protected from direct impact of the intense radiant heat from the incandescent mass of the fire, no serious trouble ensued. In the recent cruisers built under the Naval Defence Act of 1889, a separate combustion-chamber to each furnace has been adopted with perfect success.

Boiler.—It is impossible to chronicle much change in the form of the marine boiler as designed for ordinary service; but both Messrs. Thornycroft and Messrs. Yarrow have given their attention to water-tube boilers, with the object of lightening weights and so rendering higher speeds attainable in small vessels. These boilers doubtless have the merit of lightness; but unless there are never less than two in one ship, so arranged that one boiler can readily be shut off, they can be of little use in ordinary service, as the failure of one tube is the failure of the whole boiler of which it is a part; whereas in an ordinary boiler a tube may give out, and cause no more trouble than that involved in inserting a stopper. If however tubulous boilers were used in numbers and separable, they might be made serviceable for the mercantile marine, and might give the shipowner a few more tons dead weight, and so make remunerative what might otherwise be a loss. One of the great advantages however of boilers of this type, namely the small weight of water they carry, is attended by what might prove a serious drawback, inasmuch as they have to be fed and worked with greater care; whereas the large cylindrical boiler, which contains a large reserve of water, will admit of a little irregularity. But to set against this, there is the probability that the damage might not be so serious in the water-tube boiler, if the water were allowed to become low. Moreover by the use of slow-working independent feed-pumps there is no reason why this possible source of trouble should not be overcome.

Though no particular change can be recorded in the general design of the marine boiler, the change of material used and the great advance which has taken place in the application of tools

to boiler-making cannot pass without notice. As a material for boilers, iron is now a thing of the past, though it seems probable that it will continue yet awhile to be the material for tubes. Steel making has moved on apace, so that now plates can be procured of 132 square feet superficial area and 1½ inch thick. Mechanical appliances have been greatly improved. All flanging, tapping, tubing, and staying, and in some works practically all riveting, are the work of machines; and a practical calking machine seems not quite an improbability. On the other hand, for purely boiler work, a punching machine has happily become obsolete in marine engine works. In view of these facts and of the ever-increasing knowledge of the structure, the Board of Trade and Lloyd's have relaxed some of the rules by which manufacturers were "guided," if not perhaps somewhat hampered; and have made considerable modifications in their scantlings. It is questionable however whether these bodies might not with safety still further modify their rules, and reduce the thickness of shells, and lower the tests relatively to working pressures. For some years past boilers have been built for the Royal Navy with shells 18 per cent. thinner than required by the Board of Trade and Lloyd's rules, and the test pressure, instead of being double the working pressure, is only 90 lbs. above it; and these boilers have proved perfectly satisfactory in respect of strength. While 18 per cent. lighter, it must not be supposed, in the case of thick plates at least, that they are weak in proportion; because the difficulties of manufacture and probabilities of defects in the plates increase so rapidly with thickness, that it is doubtful whether the difference of weight represents with any degree of approximation the difference of strength. This appears to be the view of the Board of Trade, whose rules require all heavy plates to be subjected to special tests. This subject was introduced by Mr. Richard Sennett at a meeting of the Institution of Naval Architects in 1888; and Mr. John Scott of Greenock, liberally taking action in the matter, subjected to hydraulic pressure a boiler shell built to Admiralty requirements, with the result that he proved with sufficient clearness that the elastic strength of the structure was capable of standing at least double the working

pressure for which the boiler was designed. Without further discussing this question at the present, it appears to the writer that the time has arrived when the Board of Trade and Lloyd's should reconsider their rules in these respects.

The increased pressures of steam have also caused attention to be directed to the furnace; and have led to the adoption of various artifices in the shape of corrugated, ribbed, and spiral flues, with the object of giving increased strength against collapse without abnormally increasing the thickness of the plate. As is well known, a thick furnace-plate is viewed by many engineers with great suspicion; and meanwhile the advisers of the Board of Trade, perhaps with great wisdom, have fixed the limit of thickness for furnace-plates at $\frac{5}{8}$ inch; but whether this limitation will stand in the light of prolonged experience remains to be seen. It is a fact generally accepted that the conditions of the surfaces of a plate are far greater factors in its resistance to the transmission of heat than either the material or its thickness. In 1878 the writer made a number of experiments on the transmission of heat through brass and iron boiler-tubes, the results of which went to show that, just so long as the surfaces were perfectly clean, the brass tubes were considerably more effective; but immediately they were reduced to the ordinary working condition of boiler tubes there was no appreciable difference in their efficiency. In 1867 Isherwood tried experiments with plates of $\frac{1}{8}$ inch, $\frac{1}{4}$ inch, and $\frac{3}{4}$ inch thickness; and he found that the thickness made no difference in the result, so far as he was able to detect. From the measured rate of the transmission of heat through thin plates and along bars of metal, it has been estimated that the resistances of the surfaces when fairly clean are about 97½ per cent. of the whole for a ½ inch steel or iron plate: so that, granted a plate free from lamination, thickness being a mere secondary element, it would thus appear that a furnace plate might be increased from ½ inch to $\frac{3}{4}$ inch thickness without increasing its resistance more than 1½ per cent. So convinced have some engineers become of the soundness of this view that they have adopted flues $\frac{3}{4}$ inch thick. Amongst those who have had the courage to take this step is

Mr. Alexander Taylor, of Newcastle-on-Tyne, who reports that after five years' work such flues have given unqualified satisfaction.

In the matter of mere size, there has not been much increase over boilers made many years ago; on the contrary, the increased pressures adopted have tended to cause a reduction in size. It is questionable whether such large boilers as those of the "Wyoming" and "Wisconsin," of 16½ feet diameter and 23 feet length, will ever again be produced. On the other hand, as the higher pressures have caused thicker scantlings, the larger boilers have become very heavy. The boilers of the R.M.S. "Empress of India," which were 16 ft. 3 ins. diameter by 19 ft. 6 ins. long, weighed 85 tons each, without furnace fittings or mountings of any description.

Engine.—The change from the principle of two-stage expansion to that of three and of four stages has been attended with corresponding modifications in the engine. Though the first two of the three-stage expansion engines were of the three-crank type which has now become the standard, yet in the earlier east-coast engines which were introduced by Mr. Alexander Taylor in 1881 the engine was simply the two-crank engine with another high-pressure cylinder added tandem to the first cylinder, Fig. 3, Plate 61; and for a year or two favours seemed divided between the three-crank engine and the two-crank tandem, the first cylinder being tandem sometimes with the second and sometimes with the third. In recent years, the tandem triple seems to have disappeared, except in cases of tripling old engines.

But perhaps the desire to economise in length of engine has given rise to more varieties of arrangement than any other single cause. For this purpose, combined with the aim of making them more accessible, the valves have been removed from the fore and aft centre line, and placed behind or in front, and worked either by one of the numerous forms of radial valve-gear, or by the link-motion and levers. It is true that by such an arrangement the length over the cylinders can be diminished; but as the extent to which the distances between the centres can be reduced is limited by the

lengths of the shaft bearings and the thicknesses of the cranks and couplings, little can be gained below the cylinders by this means. However, where length of hatch is important, such an arrangement has its value, as have also the two arrangements of cylinders shown in Figs. 4 and 5, Plate 61. In Figs. 6 to 11, Plates 61 and 62, are illustrated a variety of arrangements of three-stage expansion engines. In the application of the three-stage expansion principle to paddle engines, Mr. Rodger's arrangement of oscillating engine, Figs. 12 and 13, Plate 63, is most interesting, and has been found to work most satisfactorily.

Of four-stage expansion engines, the oldest type is that made by Messrs. Denny and by the Barrow Shipbuilding Co., Fig. 17, Plate 64, which consists simply of two pairs of cylinders working tandem. Messrs. Richardson of Newcastle adopt a four-crank engine, Fig. 18. Messrs. Fleming and Ferguson's, Fig. 20, consists of two pairs of cylinders working two cranks by means of a pair of triangular frames; this is similar in principle to Mr. Bernays' engine, Fig. 19, illustrated in the discussion upon Mr. Thornycroft's paper on high-speed steam navigation (Institution of Civil Engineers, vol. lxvi, 1881, page 147).

Two of the most common types of triple engines are those shown in Figs. 21 and 22, Plate 65, with the cylinders arranged in the sequence—high, intermediate, low; the condenser forms part of the engine framing, and the pumps are placed at the back of the condenser, and worked by levers. In the smaller engines, Fig. 21, the cylinders are rigidly bolted together; but in the larger, Fig. 22, they are free, and connected only by a pair of bar stays fixed to their centres. This is customary in order to prevent the extension of the distance between the centres when the engines are heated; but it is a point which appears more important in theory than in practice, and it is doubtful whether the greater rigidity of the bolted cylinders in the smaller engines is not a much more important feature in ordinary work.

In the navy, where, owing to the necessity for arranging all machinery below the water line in unprotected vessels, the horizontal engine formerly reigned almost supreme, vertical engines

are now almost uniformly adopted, and the necessary protection for the cylinders is obtained by an armoured hatch. In the later designs the larger engines are made open-fronted, Figs. 23 and 24, Plates 66 and 67, with standards of cast-steel at the back and wrought-steel pillars in front. Feed, bilge, and circulating pumps are worked by separate engines. For the air-pumps also separate engines have sometimes been adopted, and they possess great merits for manœuvring purposes, as the vacuum can be maintained and the condenser kept clear of water while the main engines are standing, and the latter are thus ready to answer more instantly any order which may be given. With the three-crank engine however this is of less importance than with the two-crank type.

In modern cruisers, which are designed with the view of steaming upon emergency at a very high speed and ordinarily at about half that rate, the engines become much too large for the power developed at slow speeds, and in consequence are not economical under the ordinary condition of working. In larger vessels this difficulty is met by separating each set of propelling engines into two sets of half the capacity, the one forward of the other, and so arranged that the forward set may be disconnected and the after set left to do the work. The propelling engines of the Italian cruisers "Lepanto," "Italia," "Re Umberto," and "Sardegna," and of the British cruisers "Blake" and "Blenheim," have been arranged on this plan. In smaller cruisers no such plan has been adopted, so far as the writer knows, nor would it be convenient with the limited room available; but something almost equivalent might without much difficulty be contrived, such as using the high and intermediate cylinders as a two-cylinder compound engine, and disconnecting the low-pressure cylinder, which would require to be placed forward. Such an arrangement is shown in Figs. 25 and 26, Plates 68 and 69. A similar arrangement the writer learns has recently been proposed by Mr. Macfarlane Gray (Institution of Naval Architects, Transactions 1891, page 63).

The general details of the engine have not undergone many modifications, but still they have not remained without change.

Piston-Valves. — Since higher steam-pressures have become common, piston-valves, which were referred to in the discussion upon Mr. Marshall's paper (page 491), have become the rule for the high-pressure cylinder, and are not unusual for the intermediate. When well designed they have the great advantage of being almost free from friction, so far as the valve itself is concerned. In the earlier piston-valves it was customary to fit spring rings, which were a frequent source of trouble and absorbed a large amount of power in friction; but in the writer's recent practice it has become usual to fit springless adjustable sleeves, such as are illustrated in Figs. 14 to 16, Plate 63. For this plan he is indebted to the suggestion of Mr. James Thompson of the Pacific Steam Navigation Co. These sleeves have all the advantages of the solid ring, so far as their freedom from friction is concerned; and in case of leakage they can with ease be adjusted by lining up at their joints. In smaller engines the same springless ring has been used for the pistons of the high-pressure and intermediate cylinders. It may not give such absolute steam-tightness as the spring ring; but any little leakage can be picked up in the low-pressure cylinder, and such very slight loss of efficiency as may be due to this cause should be fairly well compensated by the diminished friction of the valves. For low-pressure cylinders the writer is not much in favour of piston-valves: if fitted with spring rings their friction is about as great and occasionally greater than that of a well balanced slide-valve; while if fitted with springless rings there is always some leakage, which is irrecoverable. But the large port-clearances inseparable from the use of piston-valves are most objectionable; and with triple engines this is especially so, because with the customary late cut-off it becomes difficult to compress sufficiently for ensuring economy and smoothness of working when in "full gear," without some special device.

Valve-Gear.—This subject has received much attention. About 1880 Messrs. R. and W. Hawthorn, the firm with which the writer was then connected, commenced the use of a form of the Hackworth valve-gear, of which some modification was fitted to nearly all of their subsequent engines (Proceedings 1880, page 430). About the same

time Mr. Joy introduced his valve-gear, which is nearly if not exactly the same in principle as one of the numerous forms tried by Mr. Charles Brown. The apparent and direct advantages were: more nearly mathematically accurate distribution of steam; constant lead; and fewer parts. Indirectly these valve-gears have the advantage of shortening the engine, over the cylinders at least, because in their adaptation to the engine the valves are removed from the centre line to the front or back, whereby also they are rendered more accessible.

These advantages having turned attention to the matter, the forms of radial valve-gear became "legion." But the old fashioned link-motion, though it seemed for a time likely to disappear, still holds its own, and in all probability will continue to do so. In the distribution of steam it may not be so mathematically accurate on paper; but practically the effect is, or can be made, as good as with the best radial valve-gear. It does not give constant lead when linking up; but constant lead is not the ideal of perfect valve-setting. A constant-lead angle of the crank is more nearly what is required, for which a diminishing lead in the valve with linking up is the necessary condition. The old link-motion lends itself readily and gracefully to any modifications which may be suggested by changes in the condition of working; the radial forms do not. Besides this, the link-motion admits of simple geometrical treatment, which is generally understood even in the engine room, and is consequently a safer arrangement in the hands of the men found there. For high-speed engines the writer has strong objections to radial valve-gear, as to any motion not the most direct possible. It is true such gears are frequently fitted to high-speed engines; and in some horizontal engines for the navy, where space was an element of importance, they became almost a necessity. But the sudden shocks to which the parts are subjected are liable to cause considerable spring in the levers, of which such gears largely consist; and hence in some engines so designed the readings of valve settings are no guide as to what occurs when the engines are at work. Though this may be overcome by adding weight to the parts, yet when made sufficiently strong to be perfectly satisfactory the writer ventures to say that the link-motion will be the lighter of the two.

Crank-Shaft.—For ordinary mercantile ships the solid crank-shaft has become a thing of the past. As now built up of separate pieces shrunk together, the crank-shaft is sounder and far more reliable, though it is a little heavier.

Centrifugal Pumps have been more commonly adopted than formerly for circulating purposes, and with great wisdom, as they offer the advantage of keeping a cool condenser at all times, and may be used as a powerful auxiliary in case of bilging.

Steam-Pipes.—The failures of copper steam-pipes on board the "Elbe," "Lahn," and other vessels, have drawn serious attention both to the material and to the modes of construction of the pipes. The want of elastic strength in copper is an important element in the matter; and the three following remedies have been proposed, while still retaining copper as the material. First, in view of the fact that in the operation of brazing the copper may be seriously injured, to use solid-drawn tubes. This appears fairly to meet the main dangers incidental to brazing; but as solid-drawn pipes of over 7 inches diameter are difficult to procure, it hardly meets the case sufficiently. Secondly, to use electrically deposited tubes. At first much was promised in this direction; but up to the present time it can hardly be regarded as more than in the experimental stage. Thirdly, to use the ordinary brazed or solid-drawn tubes, and to reinforce them by serving with steel cord or steel or copper wire, or by hooping them at intervals with steel or iron bands. These have been tried, and found to answer perfectly. For economical reasons connected with winding, as well as for insuring the minimum of torture to the material during manufacture, it is important to make as few bends as possible; but in practice much less difficulty has been experienced in serving bent pipes in a machine than would have been expected.

Discarding copper, it has been proposed to substitute steel or iron. In the early days of the higher pressures Mr. Alexander Taylor adopted wrought-iron for steam-pipes. One fitted in the "Claremont" in February 1882 was recently removed from the vessel for

experimental purposes, and was reported upon by Mr. Magnus Sandison in a paper read before the North-East Coast Institution of Engineers and Shipbuilders (Transactions vol. 7, 1890–91, page 113). The following is a summary of the facts. The pipe was 5 inches external diameter, and 0·375 inch thick. It was lap-welded in the works of Messrs. A. and J. Stewart. The flanges were screwed on and brazed externally. The pipe was not lagged or protected in any manner. After eight and a half years' service the metal measured where cut 0·32 and 0·375 inch in thickness, showing that the wasting during that time had been very slight. The interior surface of the tube exhibited no signs of pitting or corrosion. It was covered by a thin crust of black oxide, the maximum thickness of which did not exceed 1-32nd inch. Where the deposit was thickest it was curiously striated by the action of the steam. On the scale being removed, the original bloom on the surface of the metal was exposed. It would thus appear that the danger from corrosion of iron steam-pipes is not borne out in their actual use; and hence so much of the way is cleared for a stronger and more reliable material than copper. So far the source of danger seems to be in the weld, which would be inadmissible in larger pipes; but there is no reason why these should not be lapped and riveted. There seems however a more promising way out of the difficulty, in the Mannesmann steel tubes which are now being "spun" out of solid bars, so as to form weldless tubes.

Cast steel has been freely used by the writer for bends, junction pieces etc., of steam pipes, as well as for steam valve-chests; and except for the fact that steel-makers' promises of delivery are generally better than their performance, the result has thus far been satisfactory in all respects. These were adopted because there existed some doubt at the time as to the strength of gun-metal under a high temperature; and as the data respecting its strength appeared of a doubtful character, a series of careful tests were made to determine the tensile strength of gun-metal when at atmospheric and higher temperatures. The test bars were all 0·75 inch diameter, or 0·4417 square inch sectional area; and those tested at the higher temperatures were broken while immersed in a bath of oil at the temperatures here stated, each line being the mean of four experiments.

TABLE 1.

Tensile Strength of Gun-metal at high temperatures.

Composition of Gun-metal.	Temperature of oil bath.	Tensile Strength per sq. inch.	Elastic Limit per sq. inch.	Elongation in length of 2 inches.
Per cent.	Fahr.	Tons.	Tons.	Per cent.
Copper 87, Tin 8, Zinc 3½, Lead 1½	50°	12·34	8·38	14·64
	400°	10·83	6·30	11·79
Copper 87, Tin 8, Zinc 5	50°	13·86	8·33	20·30
	458°	10·70	7·43	12·43

The result of these experiments was to give somewhat greater faith in gun-metal as a material to be used under a high temperature; but as steel is much stronger, it is probably the most advisable material to use, when the time necessary to procure it can be allowed.

Feed Heating.—With the double object of obviating strain on the boiler through the introduction of the feed water at a low temperature, and also of securing a greater economy of fuel, the principle of previously heating the feed water by auxiliary means has received considerable attention, and the ingenious method introduced by Mr. James Weir has been widely adopted. It is founded on the fact that, if the feed water as it is drawn from the hot well be raised in temperature by the heat of a portion of steam introduced into it from one of the steam receivers, the decrease of the coal necessary to generate steam from the water of the higher temperature bears a greater ratio to the coal required without feed-heating than the power which would be developed in the cylinder by that portion of steam would bear to the whole power developed when passing all the steam through all the cylinders. The temperature of the feed is of course limited by the temperature of the steam in the receiver from which the supply for heating is drawn. Supposing for example a triple-expansion engine were working under the following conditions without feed-heating:—

boiler pressure 150 lbs.; indicated horse-power in high-pressure cylinder 398, in intermediate and low-pressure cylinders together 790, total 1,188; and temperature of hot well 100° Fahr. Then with feed-heating the same engine might work as follows:—the feed might be heated to 220° Fahr., and the percentage of steam from the first receiver required to heat it would be 10·9 per cent.; the indicated horse-power in the high-pressure cylinder would be as before 398, and in the intermediate and low-pressure cylinders it would be 10·9 per cent. less than before, or 705, and the total would be 1,103, or 93·0 per cent. of the power developed without feed-heating. Meanwhile the heat to be added to each pound of the feed-water at 220° Fahr. for converting it into steam would be 1,005 units against 1,125 units with feed at 100° Fahr., equivalent to an expenditure of only 89·4 per cent. of the heat required without feed-heating. Hence the expenditure of heat in relation to power would be $89 \cdot 4 \div 93 \cdot 0 = 96 \cdot 4$ per cent., equivalent to a heat economy of 3·6 per cent. If the steam for heating can be taken from the low-pressure receiver, the economy is about doubled.

Other feed-heaters, more or less upon the same principle, have been introduced. Also others which heat the feed in a series of pipes within the boiler, so that it is introduced into the water in the boiler practically at boiling temperature; this is economical however only in the sense that wear and tear of the boiler is saved; in principle the plan does not involve economy of fuel.

Auxiliary Supply of Fresh Water.—Intimately associated with the feed is the means adopted for making up the losses of fresh water due to escape of steam from safety-valves, leakage at glands, joints, etc., and of water discharged from the air-pumps. A few years ago this loss was regularly made up from the sea, with the result that the water in the boilers was gradually increased in density; whence followed deposit on the internal surfaces, and consequent loss of efficiency, and danger of accident through overheating the plates. With the higher pressures now adopted, the danger arising from overheating is much more serious, and the necessity is absolute of maintaining the heating surfaces free from deposit. This can be done only by filling the boilers with fresh water in the first instance, and maintaining it

in that condition. To do this two methods are adopted, either separately or in conjunction. Either a reserve supply of fresh water is carried in tanks; or the supplementary feed is distilled from sea water by special apparatus provided for the purpose.

In the construction of the distilling or evaporating apparatus advantage has been taken of two important physical facts, namely:—that, if water be heated to a temperature higher than that corresponding with the pressure on its surface, evaporation will take place; and that the passage of heat from steam at one side of a plate to water at the other is very rapid. In practice the distillation is effected by passing steam, say from the first receiver, through a nest of tubes inside a still or evaporator, of which the steam space is connected either with the second receiver or with the condenser. The temperature of the steam inside the tubes being higher than that of the steam either in the second receiver or in the condenser, the result is that the water inside the still is evaporated, and passes with the rest of the steam into the condenser, where it is condensed and serves to make up the loss. This plan localizes the trouble of deposit, and frees it from its dangerous character, because an evaporator cannot become overheated like a boiler, even though it be neglected until it salts up solid; and if the same precautions are taken in working the evaporator which used to be adopted with low-pressure boilers when they were fed with salt water, no serious trouble should result. When the tubes do become incrusted with deposit, they can be either withdrawn or exposed, as the apparatus is generally so arranged; and they can then be cleaned.

Screw Propeller.—In Mr. Marshall's paper of 1881 it was said (page 476) that "the screw propeller is still to a great extent an unsolved problem." This was at the time a fairly true remark. It was true the problem had been made the subject of general theoretical investigation by various eminent mathematicians, notably by Professor Rankine and Mr. William Froude, and of special experimental research by various engineers. As examples of the latter may be mentioned the extended series of investigations on the French vessel "Pelican," and the series made by Mr. Isherwood

on a steam launch about 1874. These experiments however, such as they were, did little to bring out general facts and to reduce the subject to a practical analysis.

Since the date of Mr. Marshall's paper, the literature on this subject has grown rapidly, and has been almost entirely of a practical character. The screw has been made the subject of most careful experiments. One of the earliest extensive series of experiments was made under the writer's direction in 1881 with a large number of models, the primary object being to determine what value there was in a few of the various twists which inventive ingenuity can give to a screw blade. The results led the experimenters to the conclusion that in free water such twists and curves are valueless as serving to augment efficiency. The experiments were then carried further with a view to determine quantitative moduli for the resistance of screws with different ratios of pitch to diameter, or "pitch ratios"; and afterwards with different ratios of surface to the area of the circle described by the tips of the blades, or "surface ratios." As these results have to some extent been analysed and published, no further reference need be made to them now. In 1886 Mr. R. E. Froude published in the Transactions of the Institution of Naval Architects (page 250) the deductions drawn from an extensive series of trials made with four models of similar form and equal diameter, but having different pitch ratios. Mr. S. W. Barnaby has published some of the results of experiments made under the direction of Mr. J. I. Thornycroft; and in his paper read before the Institution of Civil Engineers in 1890 (vol. cii, page 74) he has also put Mr. R. E. Froude's results into a shape more suitable for comparison with practice. Nor ought Mr. G. A. Calvert's carefully planned experiments to pass unnoticed, of which an account was given in the Transactions of the Institution of Naval Architects in 1887 (page 303). These experiments were made on rectangular bodies with sections of propeller-blade form, moved through the water at various velocities in straight lines, in directions oblique to their plane faces; and from their results an estimate was formed of the resistance of a screw.

One of the most important results deduced from experiments on model screws is that they appear to have practically equal

efficiencies throughout a wide range both in pitch ratio and in surface ratio: so that great latitude is left to the designer in regard to the form of the propeller. Another important feature is that, although these experiments are not a direct guide to the selection of the most efficient propeller for a particular ship, they supply the means of analysing the performances of screws fitted to vessels, and of thus indirectly determining what are likely to be the best dimensions of screw for a vessel of a class whose results are known. Thus a great advance has been made on the old method of trial upon the ship itself, which was the origin of almost every conceivable erroneous view respecting the screw propeller. The fact was lost sight of that any modification in form, dimensions, or proportions, referred only to that particular combination of ship and propeller, or to one similar thereto; and so something like chaos was the result. This however need not be the case much longer.

In regard to the material used for propellers, steel has been largely adopted for both solid and loose-bladed screws; but unless protected in some way, the tips of the blades are apt to corrode rapidly and become unserviceable. One of the stronger kinds of bronze is often judiciously employed for the blades, in conjunction with a steel boss. Where the first extra expense can be afforded, bronze seems the preferable material; the castings are of a reliable character, and the metal does not rapidly corrode; the bronze blades can therefore with safety be made lighter than steel blades, which favours their springing and accommodating themselves more readily to the various speeds of the different parts of the wake. This might be expected to result in some slight increase of efficiency: of which however the writer has never had the opportunity of satisfactorily determining the exact extent. Instances can be brought forward where bronze blades have been substituted for steel or iron with markedly improved results; but in cases of this kind which the writer has had the opportunity of analysing, the whole improvement might be accounted for by the modified proportions of the screw when in working condition. In other words, both experiment and practical working alike go to show that, although cast-iron and steel blades as usually proportioned are sufficiently

stiff to retain their form while at work, bronze blades being made much lighter are not; and the result is that the measured or set pitch is less than that which the blades assume while at work. Some facts relative to this subject have already been given in a recent paper by the writer (North-East Coast Institution of Engineers and Shipbuilders, vol. 7, 1890–91, page 179).

Twin Screws.—The great question of twin-screw propulsion has been put to the test upon a large scale in the mercantile marine, or rather in what would usually be termed the passenger service. While engineers however are prepared to admit its advantages so far as greater security from total breakdown is concerned, there is by no means thorough agreement as to whether single or twin screws have the greater propulsive efficiency. What is required to form a sound judgment upon the whole question is a series of examples of twin and single-screw vessels, each of which is known to be fitted with the most suitable propeller for the type of vessel and speed; and until this information is available, little can be said upon the subject with any certainty. So far the following large passenger steamers have been fitted with twin screws:—

TABLE 2.

Passenger Steamers fitted with Twin Screws.

Vessels.	Length between perpendiculars.	Beam.	Cylinders, two sets in all cases.		Boiler Pressure per sq. inch.	Indicated Horse-Power.
			Diameters.	Stroke.		
	Feet.	Feet.	Inches.	Inches.	Lbs.	I.H.P.
City of New York City of Paris	525	63½	45,71,113	60	150	20,000
Majestic Teutonic	565	58	43,68,110	60	180	18,000
Normannia	500	57½	40,67,106	66	160	11,500
Columbia	463½	55½	41,66,101	66	160	12,500
Empress of India Empress of Japan Empress of China	440	51	32,51,82	54	160	10,125
Orel	415	48	34,54,85	51	160	10,000
Scot	460	54½	34½, 57½, 92	60	170	11,656

It appears to be a current opinion that the twin-screw arrangement necessitates a greater weight of machinery. This is not necessarily so however; on the contrary the opportunity is offered for reducing the weight of all those parts of the engines, of which the weight relatively to power is inversely proportional to the revolutions. This can be reduced in the proportion of 1 to $\sqrt{2}$, that is to 71 per cent. of their weight in the single-screw engine; for since approximately the same total disc-area is required in both cases with similarly proportioned propellers, the twins will work at a greater speed of revolution than the single screw.

From a commercial point of view there ought to be little disagreement as to the advantage of twin screws, so long as the loss of space incurred by the necessity for double tunnels is not important; and for the larger passenger vessels now built for ocean service the disadvantage should not be great. Besides their superiority in the matter of immunity from total breakdown, and in greatly diminished weight of machinery, they also offer the opportunity of reducing to some extent its cost. A slightly greater engine-room staff is necessary; but this seems of little importance compared with the foregoing advantages.

Weight of Machinery relatively to Power.—It is interesting to compare the weight of machinery relatively to the power developed; for this comparison has sometimes been adopted as the standard of excellence in design, in respect of economy in the use of material. The principle however on which this has generally been done is open to some objections. It has been usual to compare the weight directly with the indicated horse-power, and to express the comparison in pounds per horse-power. So long as the machinery thus compared is for vessels of the same class and working at about the same speed of revolution, no great fault can be found; but as speed of revolution is a great factor in the development of power, and as it is often dependent on circumstances altogether external to the engine and concerning rather the speed of the ship, the engines fitted to high-speed ships will thus generally appear to greater advantage than is their due. Leaving the condenser out of the

question, the weight of an engine would be much better referred to cylinder capacity and working pressures where these are materially different, than directly to the indicated power. In Table 4 appended are given the relative weights of nine triple-expansion engines, according to both modes of comparison; Nos. 1 to 6 are mercantile engines, and Nos. 7 to 9 are naval examples. It will be noticed that though the twin-screw engines Nos. 5 and 6 are the same type of engine as the single-screw engines Nos. 1 to 4, as evidenced by their weights per cubic foot of cylinder capacity, yet their engine-room weights per indicated horse-power are considerably lower by virtue of their higher speed of revolution. Comparing its predecessors with No. 9, which is a fair type of a naval engine, it will be seen that the engines usually fitted in the merchant service are about 44 per cent. heavier per unit of cylinder capacity than this engine. The low weight of boilers per unit of heating surface in Nos. 7, 8, and 9, which is about 22 per cent. less than in the mercantile examples Nos. 1 to 6, is due to careful use of material, as well as to the lighter scantlings adopted for boilers by the Admiralty.

The advantages of saving weight of machinery, so long as it can be done with efficiency, are well known and acknowledged. If weight is to be reduced, it must be done by care in design, not by reduction of strength, because safety and saving of repairs are much more important than the mere capability of carrying a few tons more of paying load. It must also be done with economy; but this is a matter which generally settles itself aright, as no shipowner will pay more for a saving in weight than will bring in a remunerative interest on his outlay. In his paper on the weight of machinery in the mercantile marine (North-East Coast Institution of Engineers and Shipbuilders, vol. 6, 1889–90, page 253) Mr. William Boyd discussed this question at some length, and proposed to attain the end of reducing the weight of machinery by the legitimate method of augmenting the speed of revolution and so developing the required power with smaller engines. This method, while promising, is limited by the efficiency of the screw, but may be adopted with advantage so long as the increase in speed of revolution involves no such change in the screw as to reduce its efficiency as

a propeller. But when the point is reached, beyond which a further change involves loss of propelling efficiency, it is time to stop; and the writer ventures to say that in many cargo vessels now at work the limit has been reached, while in many others it has certainly been passed.

Economy of Fuel.—Coming to the highly important question of economy of fuel, Table 5 gives the performances of twenty-eight three-stage expansion engines in ordinary work at sea. The average consumption of coal per indicated horse-power is 1·522 lbs. per hour. The average working pressure is 158·5 lbs. per square inch. Comparing this working pressure with 77·4 lbs. in 1881, a superior economy of 19 per cent. might be expected now, on account of the higher pressure; or taking the 1·828 lbs. of coal per hour per indicated horse-power in 1881, the present performance under similar conditions should be 1·48 lbs. per hour per indicated horse-power. In Table 6 the principal factors in the present performance of marine engines are compared with those of 1881, and also with those of 1872 as indicated in the table accompanying Sir Frederick Bramwell's paper. Compared on the same basis then, it appears that the working pressures have been increased twice in the last ten years, and three times in the last nineteen. The coal consumptions have been reduced 16·7 per cent. in the last ten years, and 27·9 per cent. in the last nineteen. The revolutions per minute have increased in the ratios of 100, 107, 114; and the piston speeds as 100, 124, 140. Although it is quite possible that the further investigations of the Research Committee on marine-engine trials may show that the present actual consumption of coal per indicated horse-power is understated in Table 6, yet it is hardly probable that the relative results will be affected thereby. The returns of the coal consumption have in all cases been taken in the same way and on the same basis as for Mr. Marshall's paper in 1881, so that whatever errors may affect the returns for the one year are likely to have affected those for the other. The probability of error lies in the statement of the horse-power indicated, which when taken directly from the ship's log is usually in excess of that

actually indicated continuously: so that the comparison of coal consumption with power is open to objection.

But there is another method, which is less objectionable, and from a shipowner's point of view the better of the two: namely to take the coal burnt as the measure of the power expended in propulsion. Thus for similar ships at similar speeds, the quotient, $\sqrt[3]{(\text{displacement}^2)} \times \text{speed}^3 \div$ coal per day, gives a coefficient of performance which represents the comparative cost of propulsion in coal expended; and this coefficient for the present year, when compared with that for 1881, will show the advance in efficiency of propulsion, and should include the improvements of both ships and machinery.

The tabular statements in Table 7 appended are from a series of reliable examples of performances at sea. If now the later performance coefficient, 14,810 in 1890, be compared with the earlier, 11,710 about 1881, it will be seen that the relative coal economies are as 79 to 100, or that today the coal economy is 21 per cent. superior to that of 1881. Against this comparison an objection may be raised that the present best practice is here compared with vessels and machinery at work in 1881, which were perhaps by no means the best practice of that date. This is true; but on the other hand it seems hardly fair to mix up with the existing class of three-stage expansion engines, which have for some years past been the standard, the two-cylinder or compound engines, which as a class have become practically obsolete so far as present manufacture is concerned. In Table 7 it will also be observed that the vessels taken as examples of present performance are somewhat larger than those for 1881: which will probably affect slightly the exact figures of the comparison, but certainly not the broad general facts.

Dimensions.—In the matter of the power put into individual vessels, considerable strides have been made. In 1881 probably the greatest power which had been put into one vessel was in the case of the "Arizona," whose machinery indicated about 6,360 horse-power. The following Table 3 gives an idea of the dimensions and power of the larger machinery in the later passenger vessels.

TABLE 3.

Dimensions and Power of Machinery in later passenger vessels.

Year.	Name of Vessel.	Diameters of Cylinders.	Length of Stroke.	Indicated Horse-Power.
		Inches.	Inches.	I.H.P.
1881	Alaska . .	68, 100, 100.	72	10,686
1881	City of Rome .	46, 86; 46, 86; 46, 86.	72	11,800
1881	Servia . . .	72, 100, 100.	78	10,300
1881	Livadia Yacht .	60, 78, 78; 60, 78, 78; 60, 78, 78.	39	12,500
1883	Oregon . .	70, 104, 104.	72	13,300
1884	Umbria . .	71, 105, 105.	72	14,320
1884	Etruria . .			
1888	City of New York	45, 71, 113;	60	20,000
1889	City of Paris .	45, 71, 113.		about
1889	Majestic . .	43, 68, 110;	60	18,000
1889	Teutonic . .	43, 68, 110.		

In war vessels the increase has been equally marked. In 1881 the maximum power seems to have been in the "Inflexible," namely 8,485 indicated horse-power. The following will give an idea of the recent advance made :—

"Howe" (Admiral class)	11,600	I.H.P.
"Italia" and "Lepanto"	19,000	„
"Re Umberto"	19,000	„
"Blake" and "Blenheim" (building) . . .	20,000	„
"Sardegna" (building)	22,800	„

It is thus evident that there are vessels at work today having about three times the maximum power of any before 1881.

General Conclusions.—The progress made during the last ten years having been sketched out, however roughly, the general conclusions may be stated briefly as follows. First, the working pressure has been about doubled. Second, the increase of working

pressure and other improvements have brought with them their equivalent in economy of coal, which is about 20 per cent. Third, marked progress has been made in the direction of dimension, more than twice the power having been put into individual vessels. Fourth, substantial advance has been made in the scientific principles of engineering.

It only remains for the writer to thank the various friends who have so kindly furnished him with data for some of the tables which have been given; and to express the hope that the next ten years may be marked by such progress as has been witnessed in the past. But it must be remembered that, if future progress be equal in merit or ratio, it may well be less in quantity, because advance becomes more difficult of achievement as perfection is more nearly approached.

TABLE 4 (*continued on next page*).

Dimensions, Indicated Horse-Power, and Cylinder Capacity, of Three-stage Expansion Engines in nine steamers.

No. of Steamer.	Single or Twin Screws.	Cylinders. Diameters.			Stroke.	Revolutions per minute.	Boiler Pressure per sq. inch.	Indicated Horse-Power.	Cylinder Capacity.	Heating Surface. Total.	Heating Surface. Per I.H.P.
No.		Inches.			Inches.	Revs.	Lbs.	I.H.P.	Cub. Feet.	Sq. Feet.	Sq. Feet.
1	Single	40	66	100	72	64·5	160	6,751	522	17,640	2·62
2	Single	39	61	97	66	67·8	160	5,525	436	15,107	2·73
3	Single	23	38	61	42	83	160	1,450	109	3,973	2·73
4	Single	17	26½	42	24	90	150	510	30	1,403	2·75
5	Twin	32	54	82	54	88	160	9,625	508	20,193	2·10
6	Twin	15	24	38	27	113	150	1,194	55	3,200	2·68
7	Single	20	30	45	24	191	145	1,265	36·3	2,227	1·76
8	Twin	18½	29	43	24	182·5	140	2,105	66·2	3,928	1·87
9	Twin	33½	49	74	39	145	150	9,400	319	15,882	1·62

Nos. 7 and 8 had navy boilers. No. 9 had three double-ended and two single-ended boilers.

TABLE 4 (*continued from opposite page*).

Weight of Three-stage Expansion Engines in nine steamers in relation to Indicated Horse-Power and to Cylinder Capacity.

No. of Steamer.	Weight of Machinery.			Relative Weight of Machinery.					Type of Machinery.
				Per Indicated Horse-Power.			Engine room. Per cub. ft. of Cyl. capacity.	Boiler room. Per 100 sq. ft. of Heating surf.	
	Engine room.	Boiler room.	Total.	Engine room.	Boiler room.	Total.			
No.	Tons.	Tons.	Tons.	Lbs.	Lbs.	Lbs.	Tons.	Tons.	
1	681	662	1,343	226	220	446	1·30	3·75	Mercantile
2	638	619	1,257	259	251	510	1·46	4·10	do.
3	134	128	262	207	198	405	1·23	3·23	do.
4	38·8	46·2	85	170	203	373	1·29	3·30	do.
5	719	695	1,414	167	162	329	1·41	3·44	do.
6	75·2	107·8	183	141	202	343	1·37	3·37	do.
7	44	61	105	77	108	185	1·21	2·72	Naval Horizontal
8	73·5	109	182·5	78	116	194	1·11	2·78	do.
9	262	429	691	62·5	102	165	0·82	2·70	Naval Vertical

Nos. 7 and 8 had navy boilers. No. 9 had three double-ended and two single-ended boilers.

TABLE 5 (*continued on next page*).

Particulars of THREE-STAGE EXPANSION ENGINES *in twenty-eight Steamers.*

No. of Steamer.	Cylinders.				Condenser.	Propeller.			
	Diameters.			Stroke.	Cooling Surface.	Diameter.		Pitch.	
No.	Inches.			Inches.	Sq. Feet.	Ft.	Ins.	Ft.	Ins.
1	40	66	100	72	11,586	22	0	28	6
2	40	66	100	72	11,586	22	0	28	6
3	39	61	97	66	11,000	20	10	26	0
4	39	61	97	66	11,000	20	10	26	0
5	23	38	61	42	2,008	16	0	17	6
6	25½	42	70	51	3,209	16	6	20	0
7	21	34	55½	36	1,447	14	0	17	6
8	22	35	59	39	1,430	15	6	15	6
9	29	45	74	54	3,900	19	6	20	0
10	31	48	82	54	4,150	19	0	19	0
11	25	41	67	48	2,800				
12	21½	36	59	42	2,000	15	0	16	6
13	32	51	82	54	12,562	16	6	23	0
14	27	44	71	48	2,800	17	9	17	6
15	29	45	74	60	4,020	19	0	24	0
16	29	45	74	54	3,850	18	0	21	0
17	23	37	64	48	2,400	16	6	18	0
18	28	44	74	51	3,700	17	9	22	9
19	23	36½	58	36	2,218	15	0	15	6
20	17,17	38	60	42	2,900	15	6	15	6
21	25	39	62	36	2,700	14	0	16	3
22	31	46	72	51	3,713	16	3	22	6
23	22½	35½	58½	39	1,750	14	7	16	6
24	25	42	68½	48	2,763	16	10	17	9
25	22½	35⅞	58½	48	3,530	15	6	18	0
26	31	50	83	60	6,860	19	0	23	0
27	32	53	87½	60	7,500	19	0	23	9
28	28½	46	75	42	3,450	16	0	21	0

(*continued on next page*) TABLE 5.

Particulars of BOILERS
in twenty-eight Steamers.

No. of Steamer.	Number.	Diameter.		Length.		Heating Surface. Total.	Fire-grate Area.	Steam Pressure. Lbs. per sq. inch.
No.	No.	Ft.	Ins.	Ft.	Ins.	Sq. Feet.	Sq. Feet.	Lbs.
1	Six	13	6	18	0	17,640	626	155
2	Six	13	6	18	0	17,640	626	155
3	Five	13	6	18	0	15,107	540	155
4	Five	13	6	18	0	15,107	540	155
5	Two	14	6	10	4½	3,972	133	160
6	Two	13	0	17	6	6,162	193	180
7	Two	13	6	10	0	3,350	99	160
8	Two	13	4	9	9	3,324	102	160
9	Three	12	5	16	9	6,875	240	160
10	Three	12	6	18	6	8,000	260	160
11	Two	12	6	16	4	4,645	142	160
12	Three	12	0	10	3	3,852	122	160
13	Four	16	0	19	0	20,192	710	160
14	Two	13	6	16	6	6,164	220	150
15	Two	14	8	16	8	6,950	196	150
16	Two	14	3	17	0	6,960	216	160
17	Two	11	9	17	0	4,715	144	180
18	Two	14	3	18	0	8,000	264	150
19	One	14	10	15	5	3,271	126	160
20	Two	12	0	15	2	4,400	168	150
21	Two	12	2	14	0	4,000	150	160
22	Three	13	0	11	4	5,076	110	150
23	One	15	0	11	9	2,338	50	160
24	Two	14	3	11	6	4,346	84	160
25	Two	13	0	11	4	3,486	63	160
26	Two	16	3¼	12	0	6,438	154	150
27	Four	14	6	11	6	8,571	210	160
28	Three	14	3¼	9	11	6,618	188	160

TABLE 5 (*concluded from preceding page*).

Results of TRIAL *of twenty-eight Steamers.*

No. of Steamer.	Revolutions per minute.	Piston Speed. Feet per minute.	Indicated Horse-Power.	Heating Surface.		Indicated Horse-Power per sq. foot of grate.	Coal burnt per sq. foot of grate per hour.	Coal burnt per I.H.P. per hour.	Remarks.
				Per I.H.P.	Per lb. of Coal per hour.				
No.	Revs.	Feet.	I.H.P.	Sq. Feet.	Sq. Feet.	I.H.P.	Lbs.	Lbs.	
1	52·2	627	4,295	4·11	2·46	6·86	11·45	1·67	H
2	51·3	616	4,402	4·04	2·55	7·03	11·14	1·584	H
3	57·3	630	3,587	4·21	2·22	6·65	12·60	1·896	H
4	57·4	631	3,822	3·95	2·14	7·08	13·02	1·841	H
5	61	427	1,120	3·54	2·02	8·43	14·75	1·75	
6	61·3	521	1,700	3·62	2·40	8·82	13·25	1·505	
7	64	384	900	3·72	2·31	9·09	14·67	1·612	H
8	70	455	1,065	3·12	2·38	10·42	13·70	1·312	
9	56	504	2,250	3·055	2·04	9·38	14·00	1·494	H
10	61·5	553	2,600	3·075	2·04	10·00	15·10	1·505	H
11	58	464	1,300	3·57	2·26	9·16	14·46	1·580	
12	67	469	1,100	3·50	2·29	9·02	13·79	1·529	
13	58·5	526	3,670	5·50	3·64	5·17	7·80	1·510	H
14	63	504	1,680	3·67	2·12	7·65	13·18	1·723	H
15	53·8	538	2,360	2·94	1·78	12·03	19·85	1·650	
16	64	576	2,550	2·73	1·82	11·80	17·70	1·500	
17	62	496	1,500	3·14	2·00	10·40	16·31	1·568	
18	62	527	1,727	4·63	2·85	10·53	17·06	1·620	
19	76	456	1,269	2·58	1·84	10·07	14·10	1·400	P
20	75	525	1,530	2·875	1·96	9·11	13·32	1·464	P
21	73	438	1,250	3·20	2·40	8·35	11·13	1·330	P
22	72	612	2,513	2·02	1·34	22·85	33·95	1·488	D H
23	76	494	1,350	1·73	1·28	27·00	36·42	1·350	D H P
24	65	520	1,800	2·41	1·94	21·42	26·62	1·242	D H P
25	69·5	552	1,360	2·56	1·91	21·59	28·90	1·338	D H P
26	59	590	2,600	2·435	1·78	16·88	23·05	1·365	D H P
27	66	660	3,400	2·52	2·04	16·18	19·97	1·234	D H P
28	73	511	2,058	3·215	2·05	17·10	10·92	1·565	
Average of all twenty-eight .				3·275	2·14	11·22	17·08	1·522	
Average of Natural draught .				3·560	2·25	8·91	13·92	1·573	
Average of Forced draught .				2·412	1·72	20·98	28·15	1·336	

D = Forced Draught. H = Feed Heater. P = Pass-over Slide-Valve.

TABLE 6.

Actual and Comparative Results of Working of Marine Engines in three years, 1872, 1881, 1891.

Boilers, Engines, and Coal.	Actual Results.			Compared with 1872.			Compared with 1881.		
	1872	1881	1891	1872	1881	1891	1872	1881	1891
Boiler Pressure lbs. per sq. inch	52·4	77·4	158·5	1·000	1·477	3·025	0·677	1·000	2·048
Heating Surface per horse-power, sq. feet	4·410	3·917	3·275	1·000	0·889	0·743	1·125	1·000	0·837
Revolutions per minute revs.	55·67	59·76	63·75	1·000	1·074	1·145	0·932	1·000	1·062
Piston Speed feet per minute	376	467	529	1·000	1·242	1·406	0·805	1·000	1·132
Coal per horse-power per hour lbs.	2·110	1·828	1·522	1·000	0·866	0·721	1·154	1·000	0·833

TABLE 7.

Performance of Machinery relatively to Coal Consumption.

$$\text{Coefficient of Performance} = \frac{\sqrt[3]{(\text{Displacement}^2)} \times (\text{Speed in knots})^3}{\text{Tons of Coal in 24 hours}}$$

No. of Vessels.	Length in feet.	Coefficients of Displacement.		Speed in knots, divided by square root of Length in feet.	Working Pressure. Lbs. per sq. inch.	Coefficient of Performance.
		Block.	Prismatic.			
Seventeen Vessels with Two-stage Expansion Engines; date about 1881.						
1–17	260 to 320	0·751	0·774	0·539	83	**11,710**
Sixteen Vessels with Three-stage Expansion Engines; date 1890.						
1	440	0·633	0·666	0·600	155	15,590
2	400	0·703	0·775	0·520	180	15,750
3	312	0·710	0·805	0·555	160	13,300
4	300	0·635	0·691	0·566	160	14,250
5	295	0·697	0·769	0·536	160	12,150
6	460	0·617	0·708	0·633	155	14,850
7	460	0·618	0·710	0·621	155	14,210
8	430	0·623	0·699	0·638	155	13,650
9	430	0·626	0·701	0·641	155	13,450
10	300	0·730	0·765	0·579	160	15,200
11	400	0·770	0·804	0·550	160	14,410
12	336	0·756	0·780	0·545	160	16,600
13	275	0·772	0·780	0·633	160	16,700
14	370	0·779	0·810	0·546	150	15,600
15	422	0·745	0·774	0·555	150	15,400
16	345	0·770	0·792	0·554	180	14,690
Means		0·699	0·752	0·579	159	**14,810**

Discussion.

Mr. F. C. MARSHALL thought the Members of the Institution were to be congratulated on having met with a gentleman of Mr. Blechynden's experience and position to give them the result of the progress during the last ten years in the development of the marine engine. The whole question seemed in the present paper to have been treated from beginning to end in a most masterly manner.

With regard to the omission (page 306) to say anything about the triple-expansion engine in his own paper in 1881, there were at that time only two instances of triple-expansion engines; and he might be pardoned if, in the midst of so many other engineering matters, those two were not then mentioned. They had indeed lain dormant from about 1874 to 1881, and up to 1881 nothing further had been done by the mechanical world in that direction. There was now however a record of enormous progress since 1881, which might be said to be unprecedented. How it had been brought about had been shown in the present paper; and the paper had begun, as it ought to do, with the boiler furnace, with regard to which it was stated (page 307) that during the last ten years the principle known as forced draught had been introduced into the larger class of vessels, having been previously known and used chiefly in torpedo vessels. On previous occasions he had mentioned a fact that seemed to be generally lost sight of, especially in the design of marine boilers, namely that forced draught was the secret of the success of the locomotive, and had been introduced by George Stephenson. But for their forced draught produced by the blast-pipe, locomotive engines would now probably be a long way behind their present development. On the occasion of his own paper in 1881, three vessels had just been completed at Newcastle with forced draught, and some of the members had then accompanied Lord Armstrong and Sir Frederick Bramwell, at the invitation of the Chinese Admiral, to witness the working of one of the vessels on the Tyne. Since that time, forced draught had become almost a universal feature in the development of marine engines. He was pleased to

(Mr. F. C. Marshall.)

find that the adoption of forced draught was regarded by the author (page 308) as reducing the coal consumption of 1·573 lbs. per I.H.P. per hour with natural draught to 1·336 lbs. with forced draught, or a saving of 15 per cent. A further effect of the introduction of forced draught had been an increase of power in each boiler of from 30 to 50 per cent.; while a still further advantage had been that the most inferior coal could be used with perfect safety. There were steamships which had been using, almost from that time to the present, nothing but slack, costing now about 5*s.* 6*d.* per ton, instead of lump coal at 12*s.* 6*d.* The arrangement of forced draught adopted had remained almost the same; there had been but little change. The inconveniences alluded to in the paper (page 307) had gradually tended to produce a dislike to the closed stoke-hold, and the substitution of the closed ashpit. There had been a good deal of discussion in scientific and professional circles regarding the evils of forced draught in connection with the boilers of the navy; but he believed Mr. White would confirm the opinion that forced draught had really nothing to do with any of the mishaps which had occurred with boilers in the navy. In this question he himself felt a kind of paternal interest, having been the first to apply forced draught in large vessels.

With regard to boilers, it had been pointed out (page 310) that there had not been much change in respect of form and design; but in another respect he thought all would agree with the author that there had been a great change. For it was impossible to go into any modern boiler shop which had kept pace with the advance of improvements without realising that a great change had come over the manufacture of boilers. The application of machinery to boiler-making, the better design of the boilers, the more careful manipulation of the material, and the introduction of the surveyor into the boiler shop in the same way that he had previously been introduced into the ship-yard—having in both cases been greatly objected to in the first instance—had all together produced a much better class of work throughout. The material now employed was altogether of a highly superior character to anything used twelve or fifteen years ago. Reference had been made (page 311) to the subject

introduced by Mr. Sennett of reduction in the thickness of shell plates: a principle which he thought might be wisely adopted by Lloyd's Committee and the Board of Trade. There was a general consensus of opinion, he believed, that a change was necessary in this respect, and that the recent great modifications in the material employed should be recognised in the existing rules, which now dated twelve or fifteen years back. The mild steel now used could be perfectly relied upon; or if it was defective in any way it was so through the fault of the surveyors. The workmanship also was as perfect as could be, every rivet-hole being drilled, every piece fitted as carefully as possible, and all the work done under the oversight of the surveyor. He could therefore confirm the author's opinion that there was no reason why it should still be compulsory to recognise large factors of safety, in order to allow for deficiencies in workmanship and for decrease in strength of material from corrosion. It was now no longer necessary to take these drawbacks into consideration. He wished it to be recognised that the excessive precaution and waste attending high factors of safety in boilers were altogether unnecessary, seeing that both the material and the workmanship could now be so fully relied upon. What ought to be done was to fix the standard for the material and the manner in which it was to be used, and then to make the rules correspond with these conditions. In the case of the Admiralty, the effect of such a course had been to reduce the thickness of boiler shells 18 per cent.; and there was no reason why the same should not be done by the Board of Trade and Lloyd's. The remark made in page 310 in relation to boilers he thought was of great importance, namely that, so long as they had been properly designed, no serious trouble had ensued. In one respect he thought the present practice in marine boilers was defective. In locomotive engines for many years past the fire-box had been made as large as it was possible to make it; whereas the attention of marine engineers he thought had been far too much directed to the extent of tube surface. If however the idea were rejected that tube surface was highly important, it would probably be much better for the boilers. It was considered by George Stephenson, and was a standing maxim with locomotive engineers,

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that the fire-box did three-quarters of the work, and that the first foot of length of the tubes did as much as all the rest. A large proportion of the tube surface might therefore easily be cut off, and the boilers still prove equally efficient.

The Hackworth valve-gear referred to in page 316 had been used by the Admiralty for the last ten or twelve years, and they had had no reason to regret it. He was surprised that it had not been more used elsewhere also, because the whole gear was so much more simple than others, as it had fewer working parts. With regard to the author's objections to radial valve-gear for high-speed engines (page 317), he had the pleasure of knowing that many high-speed torpedo-cruiser engines had been fitted by Mr. Cramp of Philadelphia with radial gear of the kind constantly used in this country, and were now working most satisfactorily.

The subject of copper steam-pipes he was glad had been included in the paper (page 318), because there had been a feeling that copper pipes were essential to marine engines. Although they were seen nowhere else, they were always seen in marine engines; and it was difficult to account for the difference. There were only two reasons that had led to their universal adoption in marine engines: one was the use of salt water, with the consequent risk of corrosion in iron or steel pipes; and the other was that copper pipes were supposed to give greater elasticity in the working of what was regarded as an elastic structure, namely a ship. It had been pointed out that the copper pipes which had been used had a tendency to become injured under certain conditions: that in brazing generally—and in his own experience in the brazing particularly of the flanges, though this had not been specially mentioned in the paper—there was a serious difficulty in connection with copper pipes. The many explosions that had taken place had occurred mostly near the brazing of the flange, showing that the brazing of the flange had something to do with the weakening of the copper at that place. It had also been shown experimentally that copper was seriously injured by being slightly overheated in the neighbourhood of the flange, where the flange had to be brazed on; and the introduction of solid-drawn copper pipes he was sorry to say did not improve the matter; for

unfortunately it was found that, as in steel ingots, so in copper ingots there were small blow-holes, which in the drawn pipe drew themselves out, not into slight injuries, but into serious injuries in the shape of slits, the pipe being slit where the blow-holes occurred. Many cases of that kind had been met with; and therefore even the introduction of solid-drawn copper did not remove the evil, which had to be remedied in the patchy way mentioned in the paper, namely by wrapping or strapping the pipes with copper or steel wire. Something better he thought might be hoped for, and that in a little time Lloyd's and the Board of Trade would issue regulations allowing the use of cast-iron, wrought-iron, or steel pipes, fitted of course under their own supervision with a sufficient number of expansion joints. For bends in particular, cast-iron or cast-steel might be used. Cast-iron pipes had been employed for many years by Mr. Douglas Hebson in Liverpool; and he knew of several vessels in which they were now being used.

In the author's proposal (page 329) to take the coal burnt as the measure of the power expended in propulsion, he entirely concurred. He also wished to say in the presence of Mr. Macfarlane Gray that for further progress in marine engineering there was a necessity for engines which would work economically at low powers (page 315). The expenditure of fuel, when large engines were working as frequently required in war vessels while cruising, was so great, that there was wanted some ready means of throwing one cylinder out of action, or disconnecting the connecting-rod, or something of that kind, which would give the opportunity of using the machinery at a low power.

The screw experiments made under the author's direction (page 323)—with which he had himself had something to do—were highly interesting; but even the description now given of these experiments and of the conclusions deduced from them he thought had not advanced the question much beyond what he had himself ventured to say on the subject in 1881, namely that the screw propeller was still to a great extent an unsolved problem. The data given by the author needed confirmation before a propeller could be designed absolutely to suit any particular ship. It was largely an

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empirical question that had to be dealt with. In regard also to the weights of marine engines as compared with their power (page 326), this question seemed to stand pretty much where it did in the statement furnished in his own paper in 1881 (page 461).

Mr. WILLIAM LAIRD, Member of Council, concurred in congratulating the Members on the paper which had now been placed before them. An application which he should like to mention of modern forced draught, successful in a commercial sense, had been made to the vessels belonging to the City of Dublin Steam Packet Company, running between Holyhead and Kingstown. This was in consequence of the circumstance that, when tenders were invited for a fresh contract for the mail service, the conditions imposed had been somewhat more exacting than those under which these boats had been working for over twenty years. There were four vessels, which were known to be in perfectly good condition, as were their engines also; and the difficulty was to make perfectly sure of their maintaining with the necessary regularity the increased speed required under the new contract. After consultation with his firm it had been decided to apply forced draught with a closed stoke-hold, and to reduce slightly the dip of the paddle wheels. The result had been that for several years past these vessels had been doing their work most satisfactorily, with the same consumption of fuel for the higher speed, and without any trouble at all in regard to the endurance of the boilers. This was no doubt due to the cause alluded to in the paper (page 309): namely ample heating surface in the furnace and in the combustion chamber, and plenty of room for the circulation of the water. The adoption of that course had practically enabled those four valuable vessels, with a slight overhauling, to do the required work, instead of its being necessary to build new vessels and put in new machinery. It was true that one new vessel called the *Ireland* had been built as a stand-by, which had a greater speed than the other four vessels; but these—the *Ulster*, *Munster*, *Leinster*, and *Connaught*—had worked perfectly satisfactorily at the increased speed obtained with forced draught. For other reasons the London and North Western

Railway Company, desiring to carry their passengers at a greater speed, had also placed in the hands of his firm the re-arrangement of two other vessels, the *Lily* and the *Violet*; and in order to obtain as great an economy of fuel as possible, it had been decided to make the engines on the triple-expansion principle. The three cylinders were vertical, and arranged more or less like the old steeple engines. In order to economise space and diminish the width of the engines across the ship, they were fitted with Joy's valve-gear. The Members visiting his works in Birkenhead the day after tomorrow would have the opportunity of seeing these engines in one of the vessels. The boilers were somewhat novel, being on the locomotive plan; and the stoke-holds were closed, the air being supplied by fans, on the principle of employing a moderate draught. One vessel which had now been at work for some months on this plan was doing exceedingly well; it had given no trouble either in the boilers or in the engines, and was burning less than half the coal that had previously been used with the old-fashioned simple condensing engines which had been taken out. Another set of three vessels working with forced draught in the stoke-holds was employed by the Great Western Railway in the service between Weymouth and the Channel Islands; and the results they were giving were so satisfactory, both for speed and economy of coal, that a fourth vessel of larger size was now being built and was nearly completed. These facts rather confirmed the author's views, and were proofs that the exigencies of modern marine service called for the application of all the improvements which from time to time were introduced. The various progressive steps that had been made during the last ten years were described in the paper in a most interesting way; and he only hoped that after the next ten years the author might be able to show still further advances, although perhaps they might not be so rapid as during the ten or twelve years just past.

Mr. WILLIAM H. WHITE, Member of Council, said it should not be forgotten that in the history of forced draught there was a chapter preceding that included in the present paper. It was indeed quite true, as he believed, that in this country the use of forced draught

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in any vessels larger than torpedo boats had first been carried out by Mr. F. C. Marshall in designing the machinery for the Chinese cruisers of which mention had been made (page 339); but it would be within the memory of many of the Members who had visited the Paris Exhibition in 1878 that in the marine collection there shown the results had been given of extensive experiments made on a large scale in connection with the French navy, with various forms of what was termed *tirage forcé*. Those experiments were largely the work of M. Bertin; and they comprised not only closed stoke-holds and under-grate draught, but also induced draught in various forms, including the use of compressed air in the form of jets introduced at the base of the funnel, so as to avoid any closing of the stoke-hold or any interference with the firing. The French were at that time already employing the plan of closed stoke-holds, which they had taken up by preference after trying those various plans in large ships; and it was the action of the French which had led the English Admiralty to go further into the matter at that time. The French had gone in at once for the closed stoke-holds. The first application of assisted draught in the English navy had been made in vessels where from the arrangement of the armament there was a great difficulty in getting a sufficient air-supply in the stoke-holds. The stoke-holds were open, but with great fan power for supplying air; and in some trials that had been made in other ships with practically the same boilers 25 per cent. more power had been obtained without any closing of the stoke-holds at all, simply by the improved supply of air due to the assisted draught. Experiments had then been made with closed stoke-holds, beginning with a ship of moderate size, and gradually working up to one in which the horse-power developed exceeded 6,000; and so gradually all the ships in the navy had come to be fitted with appliances for forced draught and with closed stoke-holds. In this way it had become practicable to get the results described in the paper (page 309) in the way of a possible increase in speed under circumstances of emergency. But it had never been intended that the ships furnished with forced-draught appliances should be worked continuously at the higher air-pressures. At an early period it had been laid down that under the ordinary

conditions of service the air-pressures in the stoke-holds when closed should not exceed half an inch of water, which he thought was not excessive as an upper limit. Going over a considerable period of years, and within this limit of pressure under ordinary working conditions—excluding boilers of the locomotive kind, in which the corresponding limit was about one inch—the experience in the navy was that, with all except a special type of double-ended boilers, there had been no difficulty whatever; and the author had exactly expressed the fact when he said (page 309) that the discredit which had fallen upon forced draught in consequence of difficulties experienced with boilers should really be borne not by the forced draught but by the particular design of boiler used. In a limited number of ships there were double-ended boilers, in which all the furnaces at both ends of the boiler delivered into a common combustion chamber. This was the kind of boiler in which, not under circumstances of extravagant air-pressure, difficulties had arisen; and these difficulties had since to a great extent been overcome by reducing the tube surface, by improving the circulation, and by protecting the tube plates in the way to which the author had properly referred (page 310). But in these boilers it was not considered advisable to apply the higher or "emergency" air-pressure, which with the ordinary marine boilers in the Admiralty service had formerly been two inches of water as a maximum. In the later designs of the ships of the navy the limit of air-pressure for circumstances of emergency had been fixed at one inch, which he believed did not exceed the pressure that had been used continuously on Atlantic voyages in some of the finest passenger steamers running between Liverpool and the United States. In confirmation of the opinion that the trouble experienced with certain boilers was a question of boiler design and not of forced draught, the further important fact might be mentioned, that in one class of ships where every condition was identical—except that in the earlier vessels a combustion chamber common to all the furnaces was adopted, while in the later each furnace had its own separate combustion chamber—whereas difficulties had arisen in the earlier vessels with the common combustion chamber, no difficulty whatever had arisen

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in the later vessels with the separate combustion chamber. This difference occurred in boilers of identical dimensions working at the same steam-pressure, even when the air-pressure in the stoke-holds of the later vessels had been fully two inches. It was only right in the interests of progress that these facts should be recognised, because forced draught had in many minds been charged with troubles which were only indirectly associated with it. The question of how best to apply assisted draught, as he should prefer to call it rather than forced draught, was of course one largely for experience to answer. In the navy closed stoke-holds had hitherto been used; and from his own personal observation when he had been afloat on various ships of the navy he had found that it was an arrangement which the stokers liked. He had repeatedly known the stokers close themselves down for the sake of comfort; and he had himself gone from the engine-room into the stoke-hold to be more comfortable. Of course there were objections to the several plans. If the stoke-hold were closed and the air delivered under pressure, air-locks were rendered necessary, with less easy entrance and exit; but then there was no trouble whatever in the stoking. If the under-grate draught were used, the blast must be shut off when firing. If the induced draught were employed, it had to be obtained by jets of compressed air or steam discharged into the base of the funnel, or by an exhausting fan producing suction at the same place. The latter plan had been worked out with great success by Mr. W. A. Martin of London, and had been experimented upon in the navy, and it was proposed to experiment upon it still further. With either of these plans difficulties must of course be expected in maintaining the appliance in full working order. In the Admiralty there was no other desire whatever than to get the best thing that could be obtained at any time, and to give the machinery of the navy the greatest possible efficiency. The authorities he hoped had no prejudices in the matter; they certainly were not above learning wherever there was a lesson to be learnt.

The lightness of the machinery in the navy was partly due to the circumstance already explained, namely that for the boiler shells of the navy such thicknesses were not adopted as were common in

the mercantile marine; and so far as experience extending over several years could be taken as a guide, the change to thinner shells had been fully justified by the performances of the boilers. The lightness of the engines themselves was due in a great measure to a circumstance to which he thought sufficient importance had not been attached in the paper, but which really exercised a great influence: namely that in regard both to the ships and to the machinery the fullest possible advantage was taken by the Admiralty of whatever could be done in the way of progress at any time by the makers of the materials, and they were prepared to pay more in first cost, if they could get, either in the form of forgings or castings or in any other way, an arrangement of material which would give the best combination of strength with lightness. In the mercantile marine he thought the author would agree with him that in the later examples of engines a considerable improvement had been made in the same direction, by the developments of steel manufacture, and particularly steel castings, which the Admiralty had consistently utilised for many years at great cost. The aim in the navy was not to carry any material that was not doing work, even if its removal had to be paid for.

While it was not an unknown occurrence to have break-downs in the machinery of the navy, neither were similar accidents unknown in the mercantile marine; but to the latter it was not considered worth while to give the same prominence which was given as a matter of course to the former, and which was justified by the interest that the country took in the navy. But over a long period of years he was not aware of more than one or two cases in which the accidents in the navy had been of a serious nature or had affected the main engines. As a rule they had been confined to parts of an auxiliary or subordinate kind; and they had not occurred in parts which were commonly supposed to be so much lighter than the corresponding parts in the engines of the mercantile marine. In fairness to those who had charge of the machinery afloat it should be borne in mind that great difficulty arose from the engines being so rarely worked at full power. Reference had been made in the paper (page 309) to vessels of the cruiser class, which on an emergency

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could develop a maximum of over 9,000 horse-power, but as a rule were developing only from 1,000 to 1,500 horse-power. In their fleet manœuvres and in ordinary navigation the latter would be about the range of power; and only occasional trials were made of the maximum power, either quarterly or half yearly. It would readily be understood what must therefore be the difficulty to the engineers in charge of maintaining the same efficiency and readiness in all respects for developing a high power in ships working so much below it under ordinary circumstances: as contrasted with the state of things existing in ships running from the port of Liverpool to cover a fixed distance, with their engines always doing their best. The conditions were altogether so different, that the difficulties with the naval engines were inherently considerable, no matter what care might be taken.

In the comparison of weight of machinery given in page 327 and Table 4 of the paper, he thought the weight which was in the ships of the navy was somewhat understated in relation to their power, because the relation was here based on the highest power, which was developed only under exceptional conditions. Some years ago he had himself compared the relation between the weight of the machinery in a vessel built for one of the leading steamship lines and the power ordinarily developed, with the relation which would have held good for a man-of-war built and engined by the same makers, and working under what might be called the conditions of full sea-going power, which were taken to be about two-thirds of the measured-mile conditions; and the difference of relative weight when so compared was not anything considerable.

The subject of twin screws was one with which he had been personally concerned about thirteen years ago; and at that time he had ventured to predict that there was coming a period in Atlantic navigation when the conditions which then existed in the navy would be reached in the mercantile marine, and that twin screws would be adopted as a matter of necessity and as a distinct advantage. That prediction, which at the time had been to some extent a speculation, had now been verified by experience with twin screws in vessels from the size of torpedo boats of less than 100 tons up to vessels of 13,000

tons displacement, and for speeds varying from 26 to 15 knots; and so far as could be ascertained under the difficulty of making exact comparisons with single screws, the balance of advantage in regard to efficiency of propulsion was on the side of the twin screws. The swiftest vessels that had yet been built, including torpedo boats, had twin screws. He had himself taken the times of a torpedo boat propelled by twin screws, which made six runs over the measured mile at a speed of 26¼ knots an hour; he did not know of any single-screw boat which had done the same. In one instance he remembered such grave doubts had been entertained of twin screws that the speed for a twin-screw vessel had been specified two knots below that which would have been guaranteed with a single screw; and at the end of the trial it was found that the speed actually attained had been one knot above what the single screw would have given. At the present time the tendency was to subdivide the power still further in war-ships. There was now building in France a vessel of great speed and great power, in which there were three sets of engines and three screws; and in the United States the same thing was being done. The matter had been carefully looked into at the Admiralty many years ago; and while recognising the possibility that the time would come when three screws might have to be substituted for two on a limited draught of water, he thought the balance of advantage was not yet sufficiently decided in favour of the change. That was one way however in which the French and American designers thought they were going to get over the inherent difficulty of the great range of power through which the engines in a war-ship were required to be capable of working. In the "Blake" and "Blenheim" (page 330), in which the power was 20,000 I.H.P., there were four sets of engines, two on each screw-shaft. This was a plan which had formerly been devised in the Admiralty, before it had been applied in any war-ships that he knew of; but it had then been set aside as an arrangement which would come in whenever much greater powers were required. Now that these higher powers had been reached, the plan had been brought into use; and it would be interesting to see what would be the best manner of dealing with these engines, which were so

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arranged that they could be separated for working under ordinary conditions. It was clear that, if the after set of engines on either shaft were to be continuously running, great care would have to be taken to keep the shaft in a true line with the forward set of engines which were being used only occasionally; and this matter was not escaping attention. The problem of working at low speeds by throwing certain cylinders out of action was also one that had by no means been overlooked. Seven or eight years ago, when he was not in the Admiralty service, he well remembered going thoroughly into this matter, with Mr. Marshall he believed, to see if it could be contrived to throw one cylinder out of action, so as to work the engines at the low powers as a two-cylinder compound instead of triple-expansion. It was found to be perfectly feasible; and their experiments at low powers showed that even large engines when so treated did not indicate quite so much waste as might be imagined. The greatest difficulty in a war-ship was one that had no concern with engineering, but altogether with tactics: namely that, even when the power had been brought down low, it was still necessary to have a large reserve of power in readiness for immediate use. It might be that for the low power one boiler would give all the steam required, and more; but the possible demands for variations in speed, necessary for station-keeping and purposes of that kind, compelled the engineers to keep other boilers alight, in order that, when the signal was suddenly given from the bridge to increase the revolutions say from 45 to 60 per minute for keeping station, it might be obeyed without hesitation. In statements as to coal consumption during manœuvres in which the speed of the fleet was perhaps only eight knots, while the possible speed that the ship possessed in order to keep station would be ten or eleven knots, he had often found that the lower power required for only eight knots was reported, instead of the higher power which would represent ten knots. As the expenditure of power varied nearly as the cube of the speed, it followed that, when nominally working at only eight knots but ready at any moment for the possibility of ten knots, the boilers must practically be generating twice as much steam as was being actually used except at occasional intervals when a spurt became

necessary. This was a matter of great interest to those engaged in designing war-ships.

Not being himself engaged in the design of marine engines, he would only add that the mercantile marine and the war fleets of this country and of the rest of the world owed a great debt of gratitude to marine engineers for what they had done during the last twenty years in the way of promoting commerce, cheapening ocean transit, and giving the power of performing long voyages at high speeds.

Mr. EDWARD REYNOLDS remarked that the proposal made by Mr. Marshall (page 343) to use cast-iron steam-pipes in ships might to some appear heretical; but in corroboration of their sufficient elasticity he might mention that his own firm had experienced no difficulty whatever in using cast-iron steam-pipes for steam-hammers. There had not been a breakage for many years, either with 15-ton hammers having 9 feet stroke, the top of which swung considerably if they struck an oblique blow; or with small hammers making 450 strokes a minute, where the vibration of the pipes was exceedingly rapid: the connection with these small hammers was made rigidly, all the movement being provided for by the elasticity of the pipes.

Mr. CHARLES COCHRANE, Past-President, in connection with the reference made in page 319 to weldless steel tubes spun out of solid bars, mentioned that he had recently seen a specimen of steel tubing which had been spun in a different way out of the molten metal by a rapid revolution, in conjunction with a gradual tilting of the vessel containing the molten steel, until at last the liquid metal took its solid form within the revolving casing, in the shape of a hollow block or cylinder from which the tube was afterwards drawn. By that plan the hopes of getting rid of the occluded gases, as he believed they were called, seemed to be great; for one of the little blocks so formed, hollow in itself, which was ready to be drawn out into a tube, had been turned down most carefully, and it revealed no signs whatever of the minute blow-holes, which had been mentioned (page 343) as such a source of danger in solid-drawn pipes produced from copper ingots. He had himself seen and examined the

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specimen so turned down, but had not witnessed the process by which the hollow block had itself been spun from the molten steel for making a weldless tube.

The reference made in page 322 to the important matter of keeping the water pure in the boilers of sea-going steamers he considered was equally applicable to many land boilers, where impure water had to be dealt with. In connection with the evaporators, a point which had not been referred to was that, by employing two or three of them in succession, the number of "effects," as they were called, could be multiplied. By diminishing the pressure from one to the other consecutively, a definite weight of steam to begin with could be made to evaporate an equal weight in the first effect, barring the loss by radiation: a similar weight in the second, by the steam coming off from the first; and again a similar weight in the third, by the steam coming off from the second. Thus with one initial quantity of steam three or four times the quantity of distilled water could be produced, compared with that obtained from a single still. This he thought was an important point in connection with land engines as well as marine engines.

The employment of twin screws he believed was attended with a collateral advantage in the opportunity which they afforded for dividing the vessel by a longitudinal bulkhead, instead of by transverse bulkheads only, in order thereby to consult the safety of the public and to make the ship unsinkable. In discussing this matter recently with the captain of one of the Union Line steamers, the latter had laughingly asked, "What about the poor captain with his vessel all on one side?" and had added that he thought he would rather see his ship go to the bottom than have to manage her when she was heeled over on one side. That of course was a difficulty with regard to which experience would have to be acquired; and perhaps it might be met by making some arrangement for filling another compartment on the other side of the ship.

Mr. J. MACFARLANE GRAY considered the paper now read was a most valuable one, which would often be referred to for many years to come. It appeared that the author had no interests of his own to

bias his views; and his sole object seemed to be to enable others to advance yet further in improving their practice.

In regard to the economy of forced draught (page 308), there might be convenience in it, but there could not possibly be economy unless the elevation of temperature of the funnel gases were thereby reduced. The heating of the air was not mentioned at all in the paper, but it was said that the use of forced draught was equivalent to an economy of 15 per cent. It was properly added however that part of this economy might be due to the other heat-saving appliances with which the steamers using forced draught were fitted. In considering forced draught he thought it was important to have a clear appreciation of the advantage it really possessed. In economy of coal the only advantage which could be gained was the saving of heat from some waste source. Nearly enough for all commercial considerations, it might be taken that the calorific effect of coal, as ascertained by laboratory evaporation tests, was equivalent to 2,500° Fahr. elevation of temperature in the products of combustion on an ordinary firegrate, whatever the quality of the fuel might be. Every 25° difference of temperature represented therefore one per cent. of the calorific value of the fuel; or the percentage lost of the calorific value of the coal by the elevation of temperature in the funnel gases was always equal to 4 per cent. of that elevation of temperature in degrees Fahr. The unit in this comparison was the total heat value of the fuel, as in a laboratory experiment. In comparing natural draught with forced draught, say that the air was obtained at 80°; and that at the extremity of the heating surface, whether in the boiler or in the funnel, the temperature of the gases was 705° with the natural draught and 580° with the forced draught. The comparison then worked out thus:—the elevations of temperature were respectively 625° and 500°; with natural draught 25 per cent. was wasted, leaving 75 per cent.; while with forced draught 20 per cent. was wasted, leaving 80 per cent. The difference was therefore 5 on 75, or 6⅔ per cent. in favour of forced draught. This was a good result, but it was less than half of 15 per cent. In this example the temperature of the chimney gas was reduced 125°, and that of the ashpit air increased 125°; but the saving in elevation of temperature

(Mr. J. Macfarlane Gray.)

must not be regarded as 250°, because the 125° could be counted only once. If the air were supplied by forced draught, the great difference of temperature between the funnel and the atmosphere was no longer required for producing the draught, and the temperature in the funnel might therefore be reduced by increasing the heating surface in the boiler. Advantage could not well be taken both of forced draught and of heated air to increase thermal economy; because if the temperature in the funnel were reduced, a larger extent of heating surface would be required for producing only a small increase of temperature in the entering air. If the quantity of air admitted per pound of coal were reduced, that would in itself be a source of economy; but then, the smaller the quantity of air, the less gain would there be by reducing the waste temperature. If the air were reduced to the theoretical quantity absolutely required for chemical union, say 12 lbs. of air per lb. of coal, it would require 48° increase of temperature in order to make a difference equal to one per cent. of the heat of the fuel. There was no doubt an economy in forced draught if cheaper coal could be got. But if this was called progress, what was the goal towards which it was tending? and would it be altogether an advantage? Apart from the Admiralty requirements, which were imperative in demanding forced draught, the goal appeared to him to be an increase in the price of the slack which was at present wasted: so that ultimately the advantage would all be with the coal-owner.

In page 310 it was remarked, in reference to the construction of boilers for working with forced draught, that the extent of the heating surfaces of the furnaces and combustion chambers must be sufficient to absorb a large proportion of the heat before the products of combustion reached the tubes; otherwise the use of forced draught would result in burning more coal than corresponded with the limit of heat which the surfaces were capable of taking up and transmitting to the water. For the efficiency of the heating surface in a boiler Professor Rankine had given the formula $(T_1 - T)^2 \div A$, where T_1 and T were the temperatures in the hot gases and in the water respectively, and A was a constant ranging from 160 to 200: that is, the heat-units absorbed per hour per square foot of heating surface

were represented by the square of the difference of the two temperatures divided by 160 to 200. That was a plain rule, and the only question was whether it was right; it had been thought out by Professor Rankine, who no doubt had had a good reason for stating it; but he did not know that it had as yet been verified. A useful formula with narrower range of constant was desirable.

As to the lightness of engines and boilers, this of course was a question of importance to the navy, especially the lightness of boilers; but he thought it would be a great pity to make them any lighter than they now were in the shells. The ship-owner who first went in for lighter boilers would have a little advantage for a time, but he would also be running a risk. Even if he were right, the temporary advantage would be taken from him by his neighbours as soon as they saw that he had been successful; and it would be no advantage to him ultimately.

In the use of corrugated flues for furnaces he had found it had commonly been supposed that all the advantage consisted in getting an increased extent of heating surface in the corrugations; and that, if the additional strength required were obtained by making the plate thicker, the conductivity of the iron would thereby be diminished. Those however he considered were two fallacies. Although there was indeed an increase of surface, yet there was no increase of heating surface in the corrugations, because the heat received by the crown of the furnace from the incandescent fuel was almost entirely radiant heat, and radiant heat moved in straight lines; and just as in the case of rainfall upon an uneven surface, no more heat would fall upon the corrugation or would be received by it than would be received by a plane surface which covered the corrugation. The notion that the conductivity of the metal was greatly impaired by its thickness was also a fallacy. It used to be believed that the thickness of the metal was a matter of importance in this respect; but the modern view, which was now held by all who had studied the subject, was as stated in the paper (page 312), that the resistance to the transmission of heat through a metal plate consisted almost entirely in the resistance which the heat met with at the surface, in trying to pass from one medium into another, that

(Mr. J. Macfarlane Gray.)

is, in getting from the air into the iron, and again in getting from the iron into the water. It was as if the heat wavelets had to change their step. They were proceeding at a certain step in the air; and then they had to change their step to get into the iron. It seemed as if they had to think about it, and hesitated before they changed step and got into the iron; and then they had to change again, and hesitated again, in getting into the water. It was there that the resistance occurred. He did not know that there was any rule directly limiting the thickness of furnace-plates of steel or ingot iron to 5-8ths inch (page 312). There was a crushing limit stated, about two tons per square inch on steel furnace-plates; and as this was reached at 5-8ths inch thickness with furnaces 6 feet long, perhaps what the author meant was that up to say 5-8ths inch the pressure allowed was proportional to the square of the thickness, and above this thickness it was proportional to the thickness simply.

In page 315 his name had been mentioned in connection with a proposal for cutting off the low-pressure cylinder for working at low power; and in reference to Mr. White's remarks on this subject (page 352) he understood it had not been attempted to experiment in the navy with leaving off the low-pressure cylinder, but one of the other cylinders. This was a matter which was looked at differently by different people: by one eminent engineer he had been told that it was downright nonsense to propose anything of the kind; while another engineer had taken a great interest in the plan, in connection with the steamers which were sent out to China for tea. He stated that it did not matter how slowly they went out, but they had to come home at a high speed; hitherto they had failed to gain anything by going out slowly, and he now intended, if he could arrange it for the pumps, to disconnect the connecting-rod of the low-pressure cylinder when they went out next season. This arrangement he had been informed had already been carried out in the engines of one of the new steamers of the American navy, the "State of Maine"; and he understood from Mr. Maw that it had for a long time been tried also in Russia. Even the Russians were therefore in advance in this respect, and they were no doubt going to work in the right way for economical slow steaming.

In page 317 reference was made to the link-motion, and also to the lead of the valve varying. In this connection the simplest rule to remember was that the link should go with the engine, instead of against it: that is to say, the direction in which the link had to be shifted for starting the engine should be the same as the direction in which it was intended the crank should rotate. The link then gave an increased lead for an earlier cut-off; and this he thought ought to be so, because if the earlier cut-off were accompanied by a diminished lead, the steam would be wire-drawn. The principle of crossing the rods so that the link should go with the engine, instead of against it, was carried out in Stephenson's link-motion. At one time he had thought it was an advantage to have the rods crossed the other way, giving a diminished lead with earlier cut-off and causing the valve to remain closed when the engine was stopped; but many years ago the mistake had been pointed out to him by Mr. George Crow of Messrs. Stephenson's, and he had then made the rule for himself that if the link went with the engine the lead was increased for earlier cut-off, but if it went against the engine the lead was diminished for earlier cut-off.

In reference to the early use of wrought-iron for steam-pipes (page 318), the first notable example of wrought-iron steam-pipes for marine engines he believed was that of the "Great Eastern"; but he understood it had not proved a success, because the corrosion was so extensive. The "Great Eastern" he believed had been broken up in Liverpool; and if the state of the steam-pipes could be ascertained exactly, he thought it would be found that it was not encouraging to the use of wrought-iron. Cast-iron steam-pipes had been used in steamers where the pressures were lower; but they were as liable to accidents as copper pipes. In one of the vessels so fitted, there had been a bad accident from the bursting of a pipe when the steam was admitted, owing to water lying in a depression.

MR. JEREMIAH HEAD, Past-President, questioned the assertion (page 356) that the use of small and inferior coal would be of advantage only to the coal-owner. He had recently investigated some coal-mines in America, and had found that, the coal being of a

(Mr. Jeremiah Head.)

friable nature, not less than half of it turned out to be small. In Staffordshire he understood from Mr. Cochrane there were some collieries which yielded so much small coal that they were called "slack" collieries. If the circumstances of steam navigation had hitherto been such that only half the coal produced from coal mines generally had been available for steam-ship purposes, and if now by the aid of forced draught it was possible to use the other half consisting of small coal, the supply available was certainly doubled. How that result was going to be of no advantage whatever except to the coal-owner, he could not see. Instead of raising the price of coal, he should think it would tend to diminish it. There was the old well-known saying that any one who made two blades of grass to grow where only one blade grew before was a benefactor of the human race; and he certainly thought that engineers, who by means of forced draught or in any other way made two tons of coal available where one only could be made use of before, were equally benefactors of the human race.

Mr. W. FORD SMITH remembered that as long ago as 1847 or 1848 a steamer came to Liverpool from America, in which forced draught was applied by closing the furnaces and using a blowing fan. On asking what benefit had been obtained from the plan, he had been told that the advantage was great. The vessel was a large one, and was called the "United States"; and he had seen her when she was in the Liverpool docks.

Mr. J. HARTLEY WICKSTEED, Member of Council, asked the author to explain the mechanical action of the engine shown in Fig. 20, Plate 61, in which the piston rods were connected with the crank by means of a triangular frame.

In regard to the strength of furnace plates, considering that a beam was stiff in proportion to the square of its depth, it was clear that, if the same metal were put into a deeper form, so that it measured more from the top to the bottom of the transverse section, the beam would be stiffer to resist distortion than if the metal were distributed in a parallel form, which did not measure so much from

the top to the bottom. In that way, quite apart from the question of conductivity, a furnace plate with circumferential ribs or corrugations was stiffer than it would be with the same amount of metal, or even with a much larger amount of metal, in a thicker plain cylindrical plate.

Mr. MICHAEL LONGRIDGE thought that much confusion arose as to the merits of forced draught from the want of a clear estimation of the kind of economy obtained by its application. That forced draught rendered it possible to burn inferior coal was beyond dispute; but that it could make a ton of inferior coal produce as much heat as a ton of the best coal was not to be believed; and therefore in estimating the economy to be realised from the use of inferior coal, a shipowner would at least have to consider the extra weight of coal to be carried and trimmed, and the increased weight of ashes to be lifted. It was also beyond dispute that a given boiler and a given quality of coal would supply more steam in a given time with forced draught than without it, because more coal could be burnt with forced draught than without it. The question was whether the consumption of coal increased more slowly, or at the same rate, or more rapidly than the production of steam; and the test was the weight and temperature of the escaping gases. Every pound of coal represented a certain number of units of heat, say for example 14,000. Of these a certain portion, say 1,000 units, would be lost by radiation; and another portion, say 1,000 units, by drawing unburnt coal out of the fires when cleaning. There would thus remain, say 12,000 units of heat; of which a part would pass through the plates into the water, and the remainder would escape up the chimney; and it was evident that, if the part carried up the chimney was increased, the part absorbed by the water would be diminished, that is to say a larger percentage of the coal would be wasted. The question then was whether the weight and temperature of the chimney gases were increased by the use of forced draught. At first sight it would appear that they must be, because with forced draught more coal was burnt per square foot of heating surface, and therefore the temperature of the chimney gases would be higher. This was the view he himself had at first

(Mr. Michael Longridge.)

taken. But experiment had led him to question its correctness. From evaporative tests of boilers in ordinary work with chimney draught he had been endeavouring to ascertain the rate of transmission of heat through boiler plates per square foot per degree of difference in temperature on the two sides, measuring carefully the coal and water and chimney gases; and he had found the transmission to vary from about 4 to 6 units per square foot per hour for each degree Fahr. of difference in temperature. He had also calculated the same coefficient from the published experiments of Professor Kennedy and Mr. Donkin and others, with the same results. Now in the boiler of a locomotive working with a blast the rate of transmission was supposed to be about 11 units per square foot per degree per hour, or nearly twice as great as in boilers working with an ordinary chimney draught. The difference he thought had not anything to do with the type of boiler; for one of Messrs. Kennedy and Donkin's experiments on a locomotive boiler with ordinary draught gave a coefficient rather lower than 4 units. Was the higher rate of transmission in the locomotive with the blast in any way connected with the higher velocity of the gases passing over the heating surface? It was well known that, in heating water with steam or in condensing steam, the rate of transmission of heat was materially increased by a higher velocity of the currents. If the same thing occurred in transmitting heat from gas to water through the plates or tubes of a boiler, it was possible that, with a forced draught and a high velocity through the flues, more heat might be transmitted per square foot per degree of difference in temperature than with natural draught and a lower velocity. Experiments with ordinary draught seemed to point in this direction; for the coefficient of transmission appeared to increase with the quantity of coal burnt per square foot of heating surface, and with the quantity of air burnt per pound of coal. It might therefore be possible that owing to the higher rate of transmission more coal might be burnt in a given boiler with forced draught than without it, and yet the temperature in the chimney might not be materially increased, while the percentage of heat lost by radiation, and the percentage of unburnt coal in the ashes, would undoubtedly be reduced. Hence it seemed to him that

there might be some economy, or at all events no loss, from using a higher water-gauge pressure. In calculating the coefficient of transmission a very speculative quantity had to be dealt with, namely the temperature of the furnace. For this calculation reference had been made by Mr. Gray (page 356) to Rankine's rule, which assumed that the transmission varied as the square of the difference of temperature; but he did not see that there was any more satisfactory reason for supposing that the transmission varied as the square than for assuming that it was proportional to the first power of the difference of temperature. The latter was the assumption he had made the basis of his own calculations, because it was clear that in taking the square of the difference any errors in the estimation of the furnace temperature would have a far greater influence on the results; and the coefficients obtained would be likely to be even more erratic than they unfortunately were. On these grounds among others, it seemed to him that theoretical reasoning, based upon a rate of transmission which was assumed to be unaffected by the velocity of the gas currents, was not conclusive; and that there might after all be some intrinsic economy in forced draught, apart from quality or price of coal and from first cost of boilers and space occupied by them.

Sir JAMES N. DOUGLASS, Vice-President, having had some experience at sea with a vessel carefully fitted with forced or assisted draught, considered that, apart from the theoretical aspect of the question, there was a great deal in it of a practical nature. A ship not provided with assisted draught was subject to all the fluctuations of the atmosphere. One day the engineer would report that there had been a capital draught, and that everything was satisfactory as far as combustion went, the coal having done its work well; while another day he could do nothing with the fires, and everything was against them, and he was simply poking the coal through the fire-bars and wasting it, especially if it was not of the first quality. Again, it was well known that sometimes the starboard boiler might be working well, while it seemed as if nothing could be done to make the port boiler work efficiently. With assisted draught

(Sir James N. Douglass.)

a ship had the means of producing satisfactory combustion every day, which must have a great deal to do with economy; and the air-pressure could be varied from $\frac{1}{4}$ inch up to 2 inches of water, to meet the contingencies. Looking at the matter from a simple practical point of view, he considered there was much to be said in favour of forced draught; and if it were not attempted to carry it too far, he maintained that in its present aspect it was a valuable adjunct to ocean navigation.

Mr. BLECHYNDEN said that, in referring to the question of forced draught, Mr. Macfarlane Gray had expressed the opinion, on certain grounds of his own (page 355), that there could not possibly be economy unless the temperature of the funnel gases were thereby reduced. But having learnt to place more reliance upon facts than upon opinions, he hoped to be excused for differing utterly from that view. It had been shown in the paper that in the examples given those boilers which were worked with forced draught were more economical as regarded coal consumption in relation to power indicated than those worked with natural draught. These examples were given in Table 5 and summarised in page 308; and unless it could be proved that the superior economy was due to some other cause, it would be fairly certain that forced draught would get the credit of the saving. But there might also be another source of economy, referred to afterwards by Mr. Gray (page 356), in diminishing the quantity of air supplied for combustion. It was evident that, if the quantity could be reduced by 10 per cent., the temperature of the products of combustion would be increased about 10 per cent., and as the efficiency of heating surface was in proportion to some function of the difference of temperatures upon its two sides, the economy would thereby be augmented; and facts went to show that this view was sound. To the statement that the heating surface must also be increased if economy were to be attained with forced draught, he likewise demurred on the ground of facts to the contrary. For instance, experiments had been made in one vessel having four boilers of the navy type, which were fitted with forced draught applied on the closed stoke-hold principle: when two of the boilers

were tried under forced draught, it was found that with about one inch water-gauge of air-pressure the same power could be developed as with four boilers under natural draught with the same coal consumption, though in the first case each indicated horse-power was being developed on about 2·1 square feet of heating surface, while in the second 4·2 square feet were required. Thus a decided advantage in economy was shown for forced draught.

By the pass-over slide-valve mentioned in Table 5 was meant a valve with a port of the Allen or Trick kind, but so arranged that it made communication between the ends of the cylinder at the point of release. Thus part of the steam released from one end of the cylinder was made to fill the port and clearance at the other end, whereby an economy was effected. The particular make of this valve that was fitted in the examples referred to in Table 5 was that of Mr. John Thom.

In the engine shown in the diagram, Fig. 20, Plate 64, the triangular frame by which the two piston-rods were connected with the crank was a solid rigid frame, swinging on the end of the air-pump lever, and its two top corners were each attached by a link to the corresponding piston-rod, which was of course guided in a vertical line. Hence in the position shown in the diagram, with the crank on the top centre, the first effect of the movement of the crank in either direction would be to tilt the triangle, and to throw one piston higher up and draw the other down. Later on, both pistons would be moving down together, until the crank was passing the bottom centre, when the converse effect would be produced in the motion of the pistons: after which they would both move upwards together.

The introduction of the blast-pipe in locomotives, which had been ascribed by Mr. Marshall (page 339) to George Stephenson, might more justly be attributed he thought to Timothy Hackworth, or possibly to Trevithick; while perhaps, as regarded the origination of strictly *forced* draught for steam boilers, even a better case might be made out for Braithwaite and Ericsson, who had used bellows in the "Novelty."

All the results obtained from the screw experiments mentioned in page 323 had been carefully compared with practical results, and had

TABLE 8.

Weight in relation to Indicated Horse-Power, in lightest (No. 9) of three sets of naval machinery (Nos. 7, 8, 9) in Table 4, and in mercantile machinery.

Class of Machinery.	Indicated Horse-Power.			Weight of Machinery.			
	Maximum power.	Natural-draught power.	Ordinary power.	Total.	Per I.H.P. for Maximum power.	Per I.H.P. for Natural-draught power.	Per I.H.P. for Ordinary power.
	I.H.P.	I.H.P.	I.H.P.	Tons.	Lbs.	Lbs.	Lbs.
Naval	*9,000*	7,200	1,500	691	172	215	1,030
Mail Steamer	9,625	8,000	7,000	1,414	330	396	452
Merchant Steamer . . .	1,600	1,450	1,050	262	366	405	534
Transatlantic Passenger Steamer	15,500	...	13,500	2,350	340	...	390
Do. do. do.	20,000	...	18,000	2,600	292	...	324

* Specified test.

(Mr. Blechynden.)

been found to agree accurately therewith; and advantage had been taken of them in designing propellers on the largest scale, with marked success. It was true however, as justly observed by Mr. Marshall (page 344), that the subject was largely empirical; and in this respect indeed it was like many other questions of considerable importance in engineering.

Attention had been called by Mr. White (page 350) to the fact that the propelling machinery adopted in the navy was no lighter, relatively to its ordinary power, than that in the mercantile marine. Not only however was it not lighter, but it was indeed far heavier, as seen from the comparison in Table 8 between the lightest (No. 9) of the three sets of naval machinery (Nos. 7, 8, 9) in Table 4, and the machinery of some mercantile vessels. From this comparison it would appear that, for the power at which it was to be worked during perhaps 95 per cent. of its whole time of running, the weight of material allowed in naval machinery was double of that allowed in the mercantile marine for the same power. Nevertheless, as the safety of the navy depended upon the certainty of the maximum power being developed without mishap, it was necessary that the allowance of weight for the full power should be sufficient to ensure no part being strained beyond safe limits. With the present weights allowed, and with economical use of the material, there was no reason why, in machinery such as that represented in the first line of Table 8, any part should be strained beyond what would be considered perfectly safe in mercantile work.

The PRESIDENT said this paper was especially interesting in Liverpool, where marine engineering had made such rapid strides. It was also acceptable as continuing the papers of Sir Frederick Bramwell and Mr. Marshall, whereby in reality an account was given of what had taken place from the commencement of steam navigation to the present time. It was now his pleasant duty to propose a cordial vote of thanks to Mr. Blechynden for his paper; and all the Members he was sure would heartily join in according it to him.

Mr. ROBERT BRUCE wrote that, although reference was made in the paper to the use of closed ashpits, closed stoke-holds, and mechanically induced draught, no examples were given of ships worked continuously at sea under these plans, whereby comparisons might be drawn. Artificial draught by means of exhausting apparatus in the uptake was one of the oldest methods of stimulating combustion; it was subject to the disadvantages of natural draught, inasmuch as the air drawn by the exhauster could not be made to distribute itself equally through each furnace and over the whole heating surface, and there was always a tendency for the hottest or strongest currents to absorb the cooler and weaker ones; there was consequently a lack of uniformity in temperature throughout the heating surfaces, and of a proper control over the distribution of the air supply. The exhausting arrangement had the effect of increasing the velocity of the hot gases, and thereby preventing them from imparting their heat to the heating surfaces so advantageously as with natural draught. Another disadvantage was that a fan dealing with hot gases could not be an economical appliance as to wear and tear; and its size for exhausting from a given range of boilers would require to be at least double that of a fan dealing with air at the temperature of the atmosphere. The closed ashpit he also considered was at variance with economical working. The air admission being restricted to the under side of the fuel on the grate, there was a lack of air to consume the volatile products, and a consequent loss of heat, with great production of smoke. Where the closed stoke-hold was employed merely as an auxiliary to boilers which were already large enough for their duty with natural draught, and was brought into use only when the weather or other conditions were unfavourable for good natural draught, the rate of combustion usual with natural draught was not exceeded. When however the closed stoke-hold was adopted for boilers intended to work with a high rate of combustion and a high power per square foot of heating surface, then the injurious nature of the plan became apparent. Altogether the continuous working of the plan was surrounded with serious practical difficulty; it was costly to begin with, and any increase of power beyond that due to

natural draught had to be obtained regardless of economy of fuel. When with forced draught was combined a proper method of controlling the distribution of the air to each furnace and ashpit, and also a simple mode of heating the air by the waste gases, any ship so fitted was able on short notice to reduce or augment the production of steam according to the power required. In relation to the work done, strong evidence in favour of forced draught as compared with natural draught was supplied in Table 5. Comparing for instance No. 11 having natural draught with No. 23 having forced draught, the former for rather less power had seemingly two double-ended boilers, entailing two stoke-holds, double mountings and fittings, and a larger number of men. The latter had only one boiler with only three furnaces, one stoke-hold, and much less dead weight in the boiler compartment, giving to the ship a corresponding increase in freight capacity; there was also a substantial saving in fuel of 14 per cent., which in some cases was even exceeded.

Mr. THOMAS L. MILLER wrote that, under the head of feed heating, figures were given in page 321 to show the economy of taking steam for this purpose from the high-pressure or low-pressure receiver; and it appeared to be concluded that the economy, as far as the boiler was concerned, was due simply to the smaller number of heat units required to be put into the water in order to convert it into steam. In addition however to the reduction in the number of heat units taken up by the water, he was of opinion that there was a further economy due to increased efficiency of the heating surface, as had been shown clearly by some experiments which he had himself conducted. In these experiments water had been passed at a given velocity through tubes surrounded by steam at a pressure of 6½ lbs. per square inch above the atmosphere and a temperature of 231° Fahr.; and it was found that, by increasing the temperature of the water passing through the tubes, the efficiency of the heating surface was increased to a marked extent, as seen from the following figures:—

(Mr. Thomas L. Miller.)

	Fahr.	Fahr.	Fahr.	Fahr.
Temperature of water before entering tubes .	43°	48°	81°	157½°
„ „ „ on leaving tubes . .	212°	212°	212°	212°
Mean temp. of water passing through tubes .	127½°	130°	146¼°	184¾°
Difference from temperature of steam . . .	103½°	101°	84½°	46¼°
Evaporation, lbs. of water per hour per square foot of heating surface . . .	20⅞ lbs.	25 lbs.	26½ lbs.	30½ lbs.
Heat-units absorbed per hour per square foot of heating surface and per degree of difference of temperature	units. 381	units. 417	units. 484	units. 780

In practice he had also noticed the same effect. In one particular instance a boiler of locomotive type, fed with cold water from the town mains, had been unable to supply steam enough; but on heating the feed-water by means of a coil in the feed-water tank with steam taken direct from the boiler, no difficulty had been experienced in keeping up the required supply of steam. This instance was similar to the concluding example given in page 321 of the paper, and clearly pointed to the fact that the plan there referred to did involve economy of fuel, for the reason indicated by the foregoing figures.

Mr. BLECHYNDEN regretted that examples were not conveniently at hand for comparing the economical results of the closed stoke-hold and under-grate systems of forced draught. It would be seen however from Mr. Laird's remarks (page 344), as well as from his own reply to Mr. Gray (page 364), that Mr. Bruce was wrong in the assertion (page 368), which moreover was not supported by figures, that with closed stoke-holds any increase of power beyond that due to natural draught had to be obtained regardless of economy of fuel. But the closed stoke-hold had its disadvantages, to which most engineers were quite alive.

With regard to Mr. Miller's interesting notes on feed heating (page 369), it appeared to him that his experiments on the rate of transmission of heat through the sides of a tube would be well worth repeating in the light of the experiments made in 1874 by Mr. B. G. Nichol of Newcastle-on-Tyne for determining the rate at which heat was transmitted through a condenser tube, with a view to obtaining exact data for proportioning the surfaces of condensers

("Engineering" 10 Dec. 1875, page 449). Those earlier experiments might be regarded as identical with Mr. Miller's, inasmuch as water was passed through the inside of a tube, and was heated by steam outside; and the experiments were made with the tube placed both horizontally and vertically. The results went to show that the amount of heat transmitted through the walls of the tube per estimated degree of mean difference of temperature increased considerably with this difference. For example:—

Estimated mean difference of temperature between inside and outside of tube	Vertical Tube.			Horizontal Tube.		
	Fahr. 128°	Fahr. 151·9°	Fahr. 152·9°	Fahr. 111·6°	Fahr. 146·2°	Fahr. 150·4°
Heat-units transmitted per square foot of surface per degree of mean diff. of temp.	units. 422	units. 531	units. 561	units. 610	units. 737	units. 823

These results were exactly contrary to Mr. Miller's. In Mr. Nichol's experiments the mean differences of temperature were estimated on the assumption that the rate of transmission was proportional to the difference of temperature on the two sides of the plate through which the heat passed; and this was evidently incorrect, and inconsistent with the results of his trials. In Mr. Miller's experiments the mean difference of temperature was estimated by taking the arithmetical mean between the initial and final differences; and this must also be incorrect, if the rate of transmission followed any regular law at all. These inaccuracies however would not account for the variation between the results of the two experimenters. Having himself been present when Mr. Nichol's experiments were made, he naturally placed some reliance upon the care with which they were carried out; and he was therefore unable to assent to the doctrine that heating surface increased in efficiency with decreased difference in temperature between the heating and the heated fluid. The increased efficiency of the locomotive boiler with the feed heater described by Mr. Miller might perhaps be accounted for by the heated feed preventing priming, as he had known to happen in other cases.

DESCRIPTION OF THE WAREHOUSE AND MACHINERY FOR THE STORAGE AND TRANSIT OF GRAIN AT THE ALEXANDRA DOCK, LIVERPOOL.

By Mr. WILLIAM SHAPTON, of London.

Since the paper read to this Institution in 1869 (Proceedings page 208) by Mr. Percy Westmacott, Past-President, on the hydraulic Machinery for Warehousing Grain at the Liverpool and Birkenhead docks, the system of carrying upon flexible canvas and rubber bands has been greatly extended and adopted, both in this country and on the Continent, and also in America. The latest example is the Silo Granary or Elevator of the Liverpool Grain Storage and Transit Co. at Bootle, Liverpool, which the Members have been kindly invited to visit on the occasion of the present meeting.

The objects aimed at in designing this granary were:—1st, the greatest storage capacity on a given area of ground; 2nd, economy of construction; 3rd, immunity from fire risk; 4th, economy of labour in the several processes of discharging from ships, reception into the granary, turning over to keep the grain in marketable condition, bagging, weighing, and delivering into railway wagons and into carts.

Building.—As shown in the general plan, Fig. 1, Plate 70, the building stands at a considerable distance from the dock side. On three sides it has direct connection with the London and North Western, Lancashire and Yorkshire, and Midland Railways, for deliveries of grain; whilst the front is occupied by the engines, boilers, and offices. The dimensions of the building in plan are 240 feet by 172 feet, within which are contained 250 hexagonal bins of brickwork, each measuring 12 feet width across from side to side in

the upper portion, Fig. 10, Plate 74, by nearly 80 feet depth inside; besides a large number of half-bins next to the main walls, which are used exclusively for delivering into sacks. The total capacity of the bins is 56,000 tons or 2,240,000 bushels. On three sides there are lean-to sheds, Figs. 4 and 5, Plates 71 and 72, in which the processes of weighing, sacking, and delivering are carried on. The foundation walls of the bins are 14 inches thick up to a height of 27 feet, above which they are carried up 9 inches thick for the remaining height of 63 feet to the top, Fig. 4. The top is covered over with a fire-proof floor, through which there are manholes with raised lips for the passage of the grain; the raised lips round the manholes are provided to prevent water from getting into the bins, in the event of the floor being flooded.

Elevators. — The grain is lifted from barges in the docks by four elevators at the dock side, and is conveyed to the granary on bands running in subways under the quay and Regent Road. At No. 1 Alexandra branch dock there are two outside elevators, Figs. 22 and 23, Plate 78, each having a nominal lifting capacity of 75 tons per hour. The grain is dredged from the hold of the barges by these elevators, lifted 43 feet, and delivered into a receiving hopper A, from which it is again lifted 32 feet by a second elevator inside the tower, where it is delivered into a second receiving hopper B. Thence it flows by gravity into a weighing hopper C underneath, which weighs two tons at a time, and delivers into a distributing hopper D beneath. This hopper holds grain enough to maintain a continuous feed to the carrying bands, and is at the same time of sufficient capacity to receive the intermittent deliveries from the weighing hopper C. Shovels or scrapers are employed in the hold for trimming the grain to the elevators. These shovels are hauled by ropes wound upon a friction winch in the tower, having an alternate reversing motion; the ropes are led into the hold through snatch-blocks, so as to travel the scrapers in a fore and aft direction alternately.

When it is desired to deliver the grain into the dock-side sheds, instead of into the bins, it is discharged either through spouts from

the top of the inside elevator, or from the distributing hopper below the weighing machine. Portable bands supported on trestles are used for conveying it to the point of storage on the floors of the sheds.

At No. 2 Alexandra branch dock there are two similar towers, Figs. 22 and 23, Plate 78, with elevators and other appliances as above described, each of 100 tons nominal lifting power per hour, but capable in practice of discharging and weighing at the rate of 145 tons per hour.

Carrying Bands.—The grain is carried from No. 1 branch dock elevators on two 18-inch bands to a point E, Fig. 1, Plate 70, near No. 2 branch dock, where it is thrown upon either one or two 28-inch bands and carried to the corner junction F, Figs. 16 to 21, Plates 76 and 77. Here it is again transferred to another pair of 28-inch bands running at right angles, which deliver it simultaneously to any two of the three 150-ton main receiving elevators, Figs. 7 to 9, Plates 73 and 74. These lift it 132 feet and deliver to three 28-inch bands on the top floor of the building. The bands have movable throwing-off machines, which can be placed in the positions required for throwing the grain into spouts that conduct it to the bins. These three 28-inch bands command the entire range of 250 bins, or an area of 40,280 square feet. For delivering, turning over, and conditioning the grain, there are five 100-ton elevators, and ten 22-inch bands; five of the latter are in subways below the bins, Fig. 4, Plate 71, and five are above.

Movable hoppers conduct the grain from the bottom of the bins to the bands which convey it to the delivery elevators, Fig. 6, Plate 72. These elevators deliver through hoppers G, H, and I, to the top bands, which carry the grain back again either to the bin whence it was drawn or to a fresh bin, thus thoroughly separating and ventilating it. For delivering into carts or railway wagons, the grain after being elevated is delivered into the receiving hopper G, from which it is run into the weighing machine H by the attendant, who looks after the filling and discharging and also records the weight. Below the weighing machine is a delivery hopper I, for receiving and

conducting the grain to the delivery bins J, Figs. 1 and 5. These bins have spouts at the bottom, passing out through the external walls of the building to the delivery sheds, where the grain is again weighed, sacked, and delivered to the carts and railway wagons.

Sack Weighing Machine.—Several methods of weighing and delivering were tried, but that which was found to give the best results and was eventually adopted is shown in Figs. 2 and 3, Plate 70. It consists in the use of a scale-beam, loaded with weights at one end, and carrying at the other a hopper which will hold one sackful or 260 lbs. of grain. A shoot conducts the grain from the bin to the hopper, which when full is emptied into the sack beneath by means of a lever opening the bottom of the hopper. The filled sack is then tied, and lowered by means of a jigger into the carts or railway trucks. The usual speed of weighing and bagging with each machine is 160 to 180 sacks per hour.

Delivery to Vessels.—For delivering grain from the granary to coasting vessels, a third band, not shown in the drawing, is laid in the subway, above the two receiving bands. This band is 16½ inches wide, and is divided into two lengths, the first running from the south-west corner of the granary to the junction F, Fig. 1, Plate 70, and thence the second continues to K at No. 1 branch dock, where there is an elevator for lifting the grain sufficiently high to shoot it over the quay in bulk into the hold of the vessel, or for weighing and delivery in bags. The carrying power of the delivery band is 50 tons per hour, and the total length 1,270 feet, or nearly a quarter of a mile. The band can be run in both directions, so that it may also be used for carrying grain to the granary.

Motive Power.—The machinery in the granary, including the first length of subway bands from the granary to the corner junction, is driven by a pair of non-condensing Corliss engines, with cylinders 27½ inches diameter by 4 feet stroke, and fly-wheel 22½ feet diameter having fifteen grooves for 5¼-inch ropes. The speed is 60 revolutions per minute. The power is sufficient to elevate and carry 600 tons

per hour; but one cylinder is sufficient for all practical purposes, so that one-half of the engine is always laid off in reserve. Steam is supplied at 70 lbs. pressure per square inch by two Lancashire boilers.

The 75-ton elevators and bands at No. 1 branch dock are driven by a semi-portable engine with two cylinders 11 inches diameter by 18 inches stroke, having a grooved fly-wheel 8½ feet diameter for rope-driving. The steam pressure is 90 lbs., and the speed 120 revolutions per minute.

The 100-ton elevators and bands at No. 2 branch dock, Figs. 22 and 23, Plate 78, are driven by a similar engine, with cylinders 14 inches diameter by 24 inches stroke, having a grooved fly-wheel 11 feet diameter, which makes 90 revolutions per minute. The steam pressure is 80 lbs.

Elevators and Bands.—The 75-ton dock-side elevators have bands 18 inches wide, and buckets spaced 15 inches apart from centre to centre. The outside leg of the elevator is 40 feet long, from centre to centre of sheaves. The 100-ton elevators at No. 2 branch dock, Figs. 22 and 23, Plate 78, have 22-inch bands, and the buckets are spaced at 15-inch centres; the outside leg is 40 feet long from centre to centre of sheaves. The 150-ton receiving elevators in the granary have 28½-inch bands; the buckets are spaced at 18-inch centres, and the legs are 128 feet from centre to centre of sheaves.

The extreme distance through which the grain is carried, namely from No. 1 dock to the granary, Fig. 1, Plate 70, is 1,680 feet, or nearly one-third of a mile; and the total length of carrying and elevator bands is 16,000 feet, or over three miles. The elevator bands run at 8½ feet per second, which is found to give the best delivery. The carrying bands run at 9 to 10 feet per second.

For hauling and shunting the railway wagons under the delivery floors, traversers and turnover capstans are employed, which are worked by hydraulic power. This power is also applied to the sack hoists or jiggers, as it was found more convenient in its direct application than steam power by means of shafting.

Silos.—The silo system of storage is common in America; but the bins are usually constructed of planks nailed one upon another. That is undoubtedly a strong form of bin, but has many disadvantages. The planks are subject to dry rot, and cannot be renewed without great difficulty. They also harbour weevils, if not frequently washed with lime. Fire risk is greatly increased, the annual premium being 21*s.* per cent., as against 3*s.* per cent. for a brick granary like that at Bootle. The importance of this difference will be appreciated when the value of the stored produce is taken into account.

Mixing.—It was found that the grain in falling into the bins left the chaff and light particles floating in the air, with the result that the stored grain was of unequal density, and in drawing off for delivery the first served got the cleanest grain, whilst the last got the largest proportion of chaff. This threatened to be a serious objection to the mode of storage, until Sprague's mixer was adopted, Figs. 10 to 15, Plates 74 and 75, which consists simply of a vertical wooden pipe or spout running down one side from top to bottom of the bin, divided all the way down by a central partition, and having openings through its sides at frequent intervals; these openings allow the grain to flow equally from all heights into each half of the spout, and to mix in its downward course through the spout.

The granary is lighted throughout by the electric light, supplied by Messrs. Holmes and Vaudry of Liverpool. The building was designed by Mr. G. E. Grayson, of Liverpool; the machinery was designed and supplied by the writer's firm, Messrs. Sir W. G. Armstrong, Mitchell, and Co.; and Messrs. Roberts and Robinson were the contractors for the building.

Discussion.

Mr. PERCY G. B. WESTMACOTT, Past-President, regretted that the author was prevented by ill health from being present; in his absence however he should be happy to answer any enquiries upon the subject of the paper. The plans now described seemed to him like old friends with a new face, more especially with regard to the bands. It was about twenty-two years ago that the first bands of this kind had been put to work in Liverpool. With regard to their mechanical arrangements there was little to be said, for the original plan had been like a healthy strong child, and he thought the main difference to be noticed in the present arrangement was that it had grown in size. The mechanical arrangements and construction of the bands were now just the same that they had been twenty-two years ago. The chief feature he considered in the granary now described was the plan of storing the grain in bins, which had been in vogue in America as much as thirty years ago he believed, but it had been a long time in coming to this country. Many attempts had been made to bring about the erection of granaries of this description; but there had always been difficulties in the way of the merchants and shippers, until the matter was taken up in Liverpool and the present large granary was put up somewhat on the American plan. It was evident that the grain, which was here never touched by hand in any portion of its progress, must be dealt with more economically than where it underwent handling to a greater or less extent.

Mr. CHARLES COCHRANE, Past-President, said that, in visiting the granary on the previous afternoon, it had struck him that some improvement might possibly be made by the adoption of a circular wrought-iron casing for the bins, instead of the hexagonal walls of brickwork 9 inches thick. Although the hexagonal form was that which filled space most perfectly, if carried out in its entirety, yet the question arose as to the material of which the hexagonal silos were constructed. The hexagonal silo of 12 feet

width across from side to side contained an area of 125 square feet; and a circle extending to the middle of the 9-inch walls of the hexagon would contain an area a trifle greater, from which however the requisite allowance would have to be made for the thickness of a circular wrought-iron casing. It seemed to him that, while economy of space was highly important in such a building, economy of cost and strength of wall had also to be taken into account; and he enquired whether the comparative cost had been considered of the hexagonal brickwork and of a circular wrought-iron casing which would give nearly the same area of bin.

Mr. J. HARTLEY WICKSTEED, Member of Council, mentioned that in the visit to the grain warehouse yesterday afternoon an excellent glass model had been exhibited of Sprague's mixer (page 377). The grain put into the glass case was in layers of different colours, so that it could be seen exactly how one layer of grain overtook another and mixed with it in its downward flow through the descending delivery pipe. It was such a beautifully simple arrangement that he thought it would be of interest if a section of the mixer were added to the illustrations of the paper, because it was quite new to himself and others who saw it. [See Figs. 10 to 15, Plates 74 and 75.] There was a spout or pipe running down the side wall of the bin, with openings in its sides at different levels; and if there was a quantity of light material at the top it flowed into the spout at the top, or if not at the top it got an entrance at the upper part through one or other of the side openings, where it was not crowded by the heavier grain. When once it had got an entrance into the spout, down it went. The model being made with a glass case, he thought the sight of that one thing alone would more than repay the time spent in a visit to the granary. There might also be other uses, he could imagine, to which this contrivance could be put.

Mr. SAMUEL E. LEE mentioned that in Limerick there was a large granary of six storeys, owned by Messrs. James Bannatyne and Sons, who also had an extensive roller mill with a capacity of

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35 sacks per hour. The granary was built in 1873, and was fitted up with elevators, conveying bands, and storage bins, in addition to storage lofts. The bins were square, built of brickwork and lined with wood. The wheat was drawn off from the bottom of the bins, and elevated to the top loft, when necessary; and then distributed to the different lofts below and to the ground floor, as required, through iron distributing pipes and branches, which were fitted with sliding doors, so that the grain could be taken from any intermediate loft for delivery from the warehouse. In consequence of a fire, the granary had subsequently to be rebuilt; and instead of carrying bands, extra sets of iron elevators had been substituted, which were placed in positions commanding the entire length of the store, and more efficiently dealing with the distribution of the grain; these elevators could raise 600 to 800 tons per day of ten hours. The granary was capable of storing 5,000 tons of wheat. All the grain taken into and delivered from the warehouse was weighed by automatic weighing machinery. The engine, driving connections, and elevators had been supplied and erected by his own firm.

Mr. JAMES PLATT asked whether the brick silos in the granary at Bootle were lined with wood or plastered, or had anything but the bare brickwork walls; and if not, whether there had been any trouble with the heating of the grain. He had known some silos erected in which there had been trouble from the moisture upon the bricks and joints heating the grain, causing it to stick to the walls in large lumps, and injuring it. The American practice was to build the silos of wood.

Mr. EDWARD B. ELLINGTON remembered that a granary called the ventilating granary had been put up about twenty-five years ago on the banks of the Thames at Rotherhithe, in which he believed the plan of storing the grain in bins had been adopted; but he did not know whether it was still being carried on at the present time. It would be of interest he thought if any information could be given as to the principles upon which that granary was constructed and worked.

Mr. EDWARD H. CARBUTT, Past-President, having visited several of the granaries in America, said that the largest in that country was at Chicago. The choice between wood and brick for the silos he thought was not entirely a question as to whether damp got into the grain and swelled it; but the foundations were bad all over Chicago, and therefore it was necessary to build the silos of wood, in order that, if the foundations gave a little, the bins could be more easily repaired. There was less difficulty in repairing a wood silo than one of brick, and he believed that was the main reason why they were built of wood. He should like to know what was the total amount of capital invested in the grain warehouse and machinery described in the paper; and also what was the total cost of moving a ton of grain: that is, taking it out of a ship, weighing it, and putting it into the bins; and what was the further cost of delivering it from the bins into trucks. That was of course an important matter. He was glad that the plan of storing in silos had been adopted in England, for the reason that the grain was thereby so much better mixed. Hitherto, as he understood, it had been the case in England that in buying grain the purchaser always got the exact grain that he did buy; whereas in America he got only whatever kind of grain might happen to be in the silo, and not any other particular kind which he might desire. The silo system meant of course a greater extent of mixing, and the purchasers did not get so large a variety of samples to select from as they would otherwise have. The main question however was that of relative cost, compared with what had been previously done, both as regarded capital outlay and as regarded the working cost per ton.

Mr. JEREMIAH HEAD, Past-President, thought that, with respect to the use of timber or brickwork in buildings of any kind, it should not be forgotten that wood of all sorts was only one-third the price in America of what it was in England, whereas brickwork was dearer there than here.

Sir JAMES N. DOUGLASS, Vice-President, mentioned that an invention appeared to be developing at the present time which he

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thought might perhaps prove serviceable for the construction of silos, namely the manufacture of light cylinders of cement. The temporary lighthouse now erected in the grounds of the Naval Exhibition in London had first stood in Liverpool at the time of the exhibition in this city in 1886, having been designed by Mr. John J. Webster, a Liverpool engineer. It was a wrought-iron structure, and the framing was originally covered with papier maché. When it was about to be re-erected in London, the question arose as to whether the same covering should be adopted again, as it was rather too expensive for the temporary purpose. It was next suggested that it might be covered with lath and plaster; but this was not considered suitable on a good iron framing. The use of expanded steel or steel trellis, invented by Mr. Golding of Chicago, was then proposed, consisting merely of thin sheets of steel, slit up as sheets of paper were slit in making fly-catchers, and then opened out in the form of netting. In this form the successive links or meshes were at right angles to the plane of the fabric, and the whole web was thus composed of a succession of deep or wide ribs, beautifully adapted for keying and supporting thin cement work. The present structure was covered with this material, and he could say from his own experience that it answered admirably, and far beyond his expectations. The plan was applicable for all forms of cement cylinders. The network was itself a good steel trellis, made by machinery at a cheap rate; and being covered with good Portland cement, it formed an excellent material for covering such a structure as the wrought-iron framing of the lighthouse. It occurred to him that this composite material would be admirably applicable for the partition walls of silos. It was largely used for partitions and similar purposes in America; and for the walls of storage bins he thought it would meet all requirements; the steel trellis made it light, strong, and rigid, while the cement rendered it impervious to moisture.

Mr. WESTMACOTT in reply said that, besides wood and brick silos, iron bins had been made in America as well as in England to a certain extent. The first iron bins tried in this country were those

at Rotherhithe alluded to by Mr. Ellington (page 380), on what was called Devaux's system of storing grain. They were square iron bins made of perforated sheet iron, with a wrought-iron perforated tube running down the centre of each. The idea was that the grain, being stored in this perforated structure, could be acted upon by an air-blast, for which an air-engine was supplied; and that, by having a plug hung upon a cord and let down inside the tube to any point, the air could be diverted at that point and blown out through the grain and through the sides of the bin. Though an ingenious idea, it was rather complicated, and it did not really work out as a commercial success. For "conditioning" grain it was much cheaper to run it out at the bottom of the bin, and give it a constitutional run on the bands, and up again through the bucket elevators, and back into the bins—which turned it over and aired it, and had the further advantage of rubbing and polishing the grain—rather than to attempt to blow the air through the grain while it was lying still. At Birkenhead there had formerly been—he did not know whether it was there still—a small plant on Devaux's system, which had been put into the grain warehouse as an experiment. Not only was the grain "conditioned" by the air blast, but it was blown from the ship's hold up to the top of the bins, the air-pressure being used for lifting the grain. The fact was however that it did not work out successfully from a commercial point of view.

As to the construction of silos, it was quite true that more space was gained (page 378) by making them of wrought-iron instead of brick; and many designs had been prepared with that object. But when the cost was gone into, and the condensation of moisture on the iron and its consequent deterioration by rust were considered, it was found that brick was perhaps the best material to use in this country, at any rate where the foundations were good. Before this was decided upon for the present granary, an experiment was tried in order to ascertain what the lateral pressure of the grain would be in a bin of that height. The experiment was tried in the warehouses already existing in Liverpool, with a wooden bin and with the means of recording the pressure of the grain both at the bottom and on the sides; and it was found that within a short height the friction

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produced by the grain against the sides eased the pressures to such an extent that there really was not any great side pressure at any part of the bin.

Allusion had also been made to mixing the grain (page 381), which was an important point. There had been a disinclination on the part of the merchant to put his grain into a warehouse where it might be mixed with somebody else's; and there was a difficulty in sorting one batch of corn, and separating it from another. Probably one merchant would have only a small quantity to store, and another a large quantity. But as soon as the American system had been adopted of parcelling or grading all the grain into certain qualities —numbering them one, two, three, four, and so on, and mixing together the whole of each quality, and selling from Nos. 1, 2, 3, 4, &c.—the matter had been facilitated so much that it had become possible to adopt this system of storing grain in this country.

The PRESIDENT proposed a vote of thanks to Mr. Shapton for his paper, which was passed; and also to Mr. Westmacott for his kindness in attending to represent the author, and to reply to the questions asked in the discussion.

Mr. SHAPTON wrote that he desired to thank Mr. Westmacott for kindly replying so fully on his behalf to the various questions asked. The silos were not lined with wood nor cemented (page 380), there being nothing but the bare brickwork of the walls. Some trouble had been experienced at first from grain sticking to the sides; but this was due to the granary being used before the brickwork had had time to dry. After a few months this difficulty disappeared, and no trouble was now experienced from this cause.

The question as to the relative cost of brick and iron silos (page 379) he was not able to answer; but the cost of the Bootle granary, excluding the subways to the dock and the dock-side elevators and all machinery, was about half that of an ordinary floor granary per quarter of storage capacity. Roughly speaking the

total cost of the Bootle granary, including machinery, land, subways to dock, barges, and machinery and buildings on dock side, was £150,000.

As an indication of the cost of working the grain (page 381), he was informed that the charge to merchants for taking grain out of a ship, weighing it, putting it into the granary, and delivering it from the bins to trucks or carts, was two shillings per ton, out of which about 1½*d.* per ton was paid for master porterage, and ten days' free rent was allowed, equal to 2½*d.* per ton: so that the net charge for receiving and delivering was 1*s.* 8*d.* per ton. Another source of revenue was rent on the storage of the grain after ten days' free rent. Since the commencement of the business it had been paying a dividend of 5 per cent., besides adding substantially to the reserve and depreciation funds.

ON THE EXPERIMENTAL MARINE ENGINE AND THE ALTERNATIVE-CENTRE TESTING MACHINE IN THE WALKER ENGINEERING LABORATORIES OF UNIVERSITY COLLEGE, LIVERPOOL.

By Professor H. S. HELE-SHAW, of Liverpool.

When the funds for building and equipping the Engineering Laboratories of University College, Liverpool, were provided by Sir Andrew Walker, Bart., it was decided by the engineering committee that one feature of the equipment should be an Experimental Steam Engine, which in Liverpool would naturally be of the marine type. It was also determined that the engine should be of such a size as would place it beyond the category of a mere model; and that it should conform to the best existing practice, so as to render it of real service to advanced as well as elementary engineering students.

The primary consideration in respect to such an engine must be its educational value. Thus elementary students need to become acquainted with the actual construction and working of a steam engine, with its valves and the different kinds of valve-motions; they should learn how to take and read indicator diagrams, to make the usual calculations in connection therewith, and to carry out dynamometer tests and other simple measurements. The more advanced students require to study the action of steam under different conditions, such as varying grades of expansion, different arrangement of the cylinders and varying clearances, steam jacketing, and varying amounts and temperature of circulating water; and to measure and note the temperatures and the condensation in various parts of the engine.

Beyond this primary aim there is the scarcely less important object of experimental research in connection with various questions which are still matters of controversy. Thus for instance, owing

to the rapid development of high pressures, the engines of many comparatively new steamers are practically obsolete, and the best modes of effecting desired changes cannot be stated with certainty without elaborate and careful experiments under conditions difficult to attain in actual practice. The invaluable experiments on Marine-Engine Trials, conducted by the Research Committee of this Institution, would seem to enable it to be now stated exactly in what way work upon such an experimental engine may supplement trials of sea-going vessels.

General Conditions.—The general conditions for such an engine may therefore be briefly stated thus. The steam-pressure must be at least as high as the highest in actual use. There must be means for conversion into triple, ordinary compound, compound with large ratio of expansion, and single engine; together with means of varying the angles of the several cranks relatively to one another; examples of the chief types of valves and valve-gear; arrangements for indicating, and taking measurements of temperature, quantity of steam and water used, quantity condensed in the jackets and casings, and actual power developed: all of which must be provided for in the most complete manner. The details of the design were originally entrusted to Mr. May, formerly chief draughtsman to the firm of Messrs. James Jack and Co., who prepared the drawings upon which tenders were invited, that of Messrs. Forrester and Co. being finally accepted. Mr. Thomas L. Miller, at that time one of the engineering staff of the college, was deputed to watch the progress of the work.

General Features of Design.—Both engine and boiler are designed to Board of Trade requirements. The engine is of triple-expansion type, to indicate 150 HP. at 150 revolutions per minute with a boiler pressure of 200 lbs. per square inch. The connection of the cylinders is (1) ordinary triple-expansion, the steam passing from high-pressure to intermediate and thence to low-pressure cylinder, and from the latter to the condenser; (2) compound with high grade of expansion, steam passing from high-pressure to low-pressure cylinder, and thence to condenser; (3) ordinary compound, steam passing from boiler to

intermediate cylinder, and thence to low-pressure cylinder and condenser; (4) single engine, using the high-pressure cylinder and condenser; (5) single engine, using the intermediate cylinder and condenser; (6) single engine, using the low-pressure cylinder and condenser. In each of these cases also the condenser can be dispensed with, and the engine worked non-condensing. The relative position of the cranks for all three cylinders is capable of alteration to different angles, so that an equivalent of tandem as well as the ordinary type can be obtained. Each cylinder is completely steam-jacketed, including the top covers and the cylinder bottoms.

In Figs. 1 and 2, Plate 79, is shown in plan and elevation the general arrangement of boiler, engine, and measuring tanks. The general arrangement of the engine itself is given in front and end elevation in Figs. 3 and 4, Plate 80, which also show the positions of the three valve-gears. The high-pressure cylinder is fitted with Stephenson's valve-gear, the intermediate with Joy's gear, and the low-pressure with Hackworth's gear. Each of these valve-gears has a graduated plate, showing the points of cut-off for different grades of expansion, and visible in conjunction with a full-size section of the corresponding slide-valve working outside the cylinder, Fig. 4. The surface condenser C and air pump A are of the usual form; the latter is driven by levers from the intermediate crosshead, with bilge and feed pumps on either side.

The power developed is measured by a brake wheel W, which also acts as a fly-wheel, and is capable of running continuously without unduly heating. Measuring tanks are provided for condensation and circulating water; and also six graduated tanks for measuring the steam condensed both in cylinders and jackets.

The boiler B, Plate 79, is of marine type, with single Fox's corrugated flue and outside combustion chamber, Figs. 13 and 14, Plate 85.

Cylinders.—In Figs. 5 and 6, Plates 81 and 82, are shown vertical and transverse sections of the cylinders. The liners for the steam-jackets are of hard cast-iron, and are made as thin as possible consistently with proper strength, so that the conduction may be as

efficient as possible. They were drawn in, and tested under hydraulic pressure both inside and outside, so as to ensure perfect jointing. The valve liners are made of phosphor bronze for the piston valves of the high-pressure and intermediate cylinders, being drawn in and bored out in place. The steam is admitted to the middle of both these valves, and exhausted at the ends. The low-pressure valve is a double-ported cast-iron slide-valve of ordinary type, placed obliquely so as to economise space in its valve-gear.

Cylinder Covers.—The covers on the top of the cylinders are box castings, Fig. 5, in order to make them steam-jackets; and they are also well lagged outside. The jacket steam is first led to these covers, and afterwards to the cylinder jackets and bottoms. Cocks are provided for shutting off the jacket steam if desired, and also for draining the water into suitable measuring tanks.

Pistons.—The high-pressure and intermediate pistons are of the Ramsbottom type, Figs. 5 and 6, Plates 81 and 82, with steel rings of 7-16ths × 9-16ths inch section, three in number. The low-pressure piston has also rings of the same kind, but they are carried in a separate cast-iron ring. Each piston is fitted top and bottom with a clearance disc, which can be removed and if desired be replaced by discs of different thicknesses, for enabling experiments to be made upon the effect of varying clearance.

Piston Rods.—The piston rods are of mild steel. The diameters of all are the same, namely 2½ inches.

Connecting Rods.—The connecting rods are of steel and of the ordinary marine type. The gudgeon pin has double the cross section of the piston rod. As in common practice, the smallest diameter of connecting rod is made equal to that of the piston rod. The two bolts for the crank-pin brasses are together rather less in area than the piston rod, and are the same diameter as the bolts in the crosshead, that is 1¼ inch diameter. Care has been taken to ensure efficient lubrication by carrying a groove nearly across the brass, so as to distribute the oil upon the crank pin.

Slipper Block.—The slipper block is forged with the piston crosshead, and is of mild steel with bronze liners, Fig. 5, Plate 81.

Crank Shaft.—The crank shaft is made of wrought-iron, and in three sections, as it is necessary to allow for change of relative position of each of the three cranks. It was considered sufficient to ensure a possibility of twelve different positions of each flange relatively to the other flange of each coupling, or twelve changes of angle through 30° each. This is effected by having twelve bolt-holes in each flange of the middle section of the shaft, and four bolt-holes in the corresponding flanges of the two outside sections. Simple as the task of obtaining this result may appear, it turned out in practice a troublesome and expensive proceeding, from the absolute necessity of a perfect fit of the four coupling bolts in every position, in order to prevent the possibility of the whole shearing force coming upon one bolt. The diameter of the shaft is 5 inches.

Bedplate.—The bedplate is cast in one piece, and is of box section, carrying upon it the condenser and the piston-rod guides. The bearings are of hard phosphor-bronze, with mild-steel caps.

Condenser.—The condenser contains 152 brass tubes of $\frac{3}{4}$ inch external diameter and 7 feet length, pitched at $1\frac{1}{4}$ inch centre to centre, that is $\frac{1}{2}$ inch more than their diameter. Their total cooling surface is 209 square feet. They are packed with screwed glands and tape packing. A steam baffle-plate is cast for each of the three exhausts, in order that the steam surrounding the tubes may be fairly spread over the cooling surface. The bottom of the condenser is well sloped to the air-pump bottom, in order to increase the efficiency of the air pump by making the condensed water flood the pump, so as to keep the foot-valve always covered. The pipes for the circulating water are made of ample size, and there is a graduated regulating valve to adjust the quantity of water. Thermometers are fitted on both the inlet and the outlet pipe with mercurial contact, the mercury being carried in pockets let into the pipe in such a way as to meet full flow of the water; and it is found that any change in

Cylinders.—The is promptly recorded. In the general plan, Fig. 1, vertical and and O are the circulating-water pipes; and the positions steam-jackets'nometers are vertically one above the other. The consistently with gs the water from the town mains through a large

Duncanson water-meter. The outlet pipe O conveys the circulating water from the condenser to the measuring tank M, the quantity used being checked by also measuring the discharge over a rectangular notch. The tank is designed with baffle-plates so as to still the water, much on the principle adopted by Mr. Bryan Donkin, Jun., in his experiments. The flow of circulating water is arranged so that the hottest water meets the hottest steam; and though this plan, which is undoubtedly correct in theory, is not entirely approved by some engineers on account of the unnecessary cooling of the feed water, it must be remembered that it is upon the extent of this cooling that the efficiency of the vacuum depends.

Air Pump.—The air pump is of phosphor bronze, its capacity being one-fifth that of the low-pressure cylinder. This is no doubt excessive for the engine, as usually worked; but not when experiments are being made with jet condensation. Kinghorn's multiplex valves are used in the pump, and the vacuum is maintained in a highly satisfactory manner. On the air-pump cover is cast a guide, in which the crosshead of the pump rod works, thus ensuring a steady motion. In order to obtain indicator diagrams from the air pump, bosses are cast on the barrel of the pump, and the various other fittings are arranged.

There are two measuring tanks, shown at F in Figs. 1 and 2, Plate 79, into one or other of which the hot-well discharge is delivered by means of a three-way cock. These tanks are of known capacity up to the point of overflow, which is visible to an observer during experiments. Directly the water coming from the hot well rises to the edge of the overflow in one tank, the three-way cock is turned so that the hot-well discharge is delivered into the other tank. At the same time the contents of the full tank are discharged through a drain cock into the feed-water tank D below. A thermometer is provided for enabling the temperature of the hot-well discharge to be observed.

Feed Pumps.—The two feed pumps are duplicates; and the metal used throughout is phosphor-bronze. The plunger is made a fit in the body of the pump, which seems to be a much better arrangement for

pumping against high pressures than leaving a large clearance, since the presence of air which leads to inefficient action is hereby avoided. The stroke is the same as that of the air pump, namely 8 inches, and the diameter 2 inches. Provision is also made for taking indicator diagrams.

Feed Check-Valves.—These are $2\frac{3}{4}$ inches diameter, so that only a small lift is required. The method of guiding the valves into their seats ensures fair wear and tear. They are in deep-seated pockets, so that they are always flooded; and the consequent hydrostatic pressure ensures uniform loading on the valve.

Relief Valve.—This is provided in case the feed check-valve on the boiler should become accidently closed. It is arranged to open when a pressure is reached 50 per cent. above that to which the safety valves are loaded.

Dynamometer Brake.—As shown in Figs. 7 to 9, Plate 83, the dynamometer brake consists of a band of cotton belting 10 inches wide, encircling the fly-wheel, which is 9 feet diameter. To the inner side of the band are attached with screws about 150 blocks of wood, 10 inches long, $1\frac{7}{8}$ inch wide, and at a distance of $\frac{1}{4}$ inch apart. Weights to the amount of 1,500 lbs. hang upon a rod in the fly-wheel pit; and by a novel arrangement the total weight can be adjusted to any required amount without the trouble and inconvenience of changing these heavy weights. This is effected by means of a screw attached to a spring balance, Figs. 8 and 9, which is in turn attached by means of two flat-link chains to the crosshead whereby the weights are fixed to the brake band. The spring balance is accurately adjusted, and reads by 2 lbs. up to 1,600 lbs. Hence by turning the handwheel H the whole or any part of the dead weight can be taken on the balance; and the difference between the reading of the balance and the 1,500 lbs. dead weight on the brake can be accurately determined. The other end of the brake band is attached to a cord, which passes to a counterpoise P over a 15-inch pulley L, Fig. 8, whose axle works on centres; by this means the weight of the lower portion of the brake band is relieved by a constant known weight; and the counterpoise P to be

subtracted in estimating the net effective weight is thus accurately determined.

In order to keep the brake cool, the fly-wheel rim is made hollow, Fig. 7, and cold water is caused to circulate continuously through it by means of the contrivance shown in Figs. 10 and 11, Plate 84. The cold water entering through the pipe A passes into the hollow rim through the pipe B, returning when heated to the centre of the wheel by the pipe C, and passing away from the wheel by the pipe D to the waste. The pipes B and C turn with the wheel, while A and D are fixed stand-pipes. The quantity of water supplied is measured by a Schönheyder meter, and the temperatures of inflow and outflow may also be determined. The actual position and method of the arrangement for working are seen on a smaller scale in Figs. 7 and 8, Plate 83.

Boiler.—In Figs. 13 and 14, Plate 85, is shown the boiler, which is of steel and of marine type, 7 ft. 3 ins. diameter and 8 ft. long over all, with a single Fox corrugated flue of steel, 2 ft. 10 ins. diameter, carried through to an outside combustion-chamber built of brick. The grate is 2 ft. 8½ ins. wide by 4 ft. 6 ins. long, say 12 square feet area. The tubes, 34 in number, are of wrought-iron, 4 inches outside diameter, and give a total surface of 279 square feet; they were tested both internally and externally. The shell is made of a single plate, great care being taken in annealing to prevent internal stresses. The proportion of the riveted joints is shown in Fig. 12, Plate 84. Steel stand-pipes are riveted to the boiler for the various mountings, care being taken to prevent the centre of more than one opening in the shell from coming on any one longitudinal line.

Besides a spring safety-valve, there is a lever valve capable of adjustment by varying weights from the lowest to the highest pressures. An injector of the influx type is fitted; and the two gauge-glasses are carried on a bracket on the wall beside the boiler.

The blow-off from the boiler is taken into a cast-iron tank T, Fig. 1, Plate 79, and thence to the drains. The tank is arranged so as to be always full of water up to within 3 inches of the top; and has a smaller overflow than would otherwise be provided, owing to the

regulations of the Corporation framed with a view to preventing steam from being blown into drains, and workmen therein possibly being scalded.

Circulating Arrangement.—The boiler has recently been fitted with a new circulating device, invented by Mr. J. M. McCulloch of Garston near Liverpool, which is shown in Figs. 15 and 16, Plate 86. It consists in placing a cock K on the front end of the boiler, below the level of the furnace, with an internal pipe extending backwards from the cock and going down to the bottom of the boiler beneath the flue. From the same cock an external pipe P passes back along the front portion of the furnace, and is continued above the fire-bars and round the bridge, and returns to the front on the opposite side of the furnace, delivering the heated water into the boiler again at the bottom.

Alternative-Centre Testing Machine.—In 1882 a description was given to this Institution by Mr. J. Hartley Wicksteed of his single-lever testing machine; and in connection with the same machine he further described in 1886 an autographic test recorder (Proceedings 1882 page 384 and 1886 page 27). Since that time various improvements have been made in the machine; and in Figs. 20 and 21, Plate 88, is shown a form differing in several important respects from any previous examples, which has been constructed by Messrs. Buckton and Co., of Leeds, for the Walker Engineering Laboratories. This machine has a wrought-iron lever 22 feet long, carrying a two-ton jockey weight or travelling poise. The fulcrum of the lever is mounted upon a cast-iron frame, which is supported by four columns 7 feet 4 inches high, instead of upon a single cast-iron standard as was the case in the earlier machines. The four columns thus serve as guides for the shackle holder and for the corresponding portions attached to the hydraulic ram.

The chief feature of the machine, and one that is entirely novel, is Mr. Wicksteed's arrangement of alternative centres, whereby the

machine may either be used for a maximum load of 100 tons, or may be made four times as sensitive with a consequent diminution of its maximum effect. In Figs. 23 and 24, Plate 89, the details of this contrivance are shown in transverse and longitudinal sections. The centre A acts as the fulcrum for the machine when testing up to 100 tons, the knife-edge of this centre being exactly 4 inches from the knife-edge C which carries the test piece. It is readily seen that the jockey weight of 2 tons must travel 2 inches from its position when the beam is balanced, in order to exert a force of one ton upon the specimen. Thus the scale for the 100-ton machine is 2 inches per ton; and 1-100th of a ton may be read by means of the vernier.

In Fig. 20 it will be noticed that there is a distance collar D under the upper spring on the pillar P, which controls the extent of movement of the lever. By removing the collar and spring, taking care of course to replace the nut and washer, and running the jockey weight back, the lever may be tipped up sufficiently high to allow the bearing carried on the shaft S, Figs. 23 and 24, to be brought under the alternative centre B. This is done by turning a hand wheel, which actuates a worm working in teeth upon the shaft S. The latter is then locked in position by screwing up the handle L, which acts as a lock nut. If the weight is now run forward sufficiently far, the beam takes its bearing upon the knife-edge B, and the other knife-edge A is lifted up out of contact with its bearing. The washer D is now replaced on the pillar P, and the lever can work only upon the centre B as a fulcrum. The distance between the knife-edges B and C is exactly 16 inches; hence the jockey weight must now move 8 inches from its position when the beam is in equilibrium on the knife-edge B, in order to exert a force of one ton upon the specimen. Thus the scale is now 8 inches per ton, that is, the machine is four times as sensitive as before; but the vernier is arranged to read to 1-1,000th of a ton.

There are two separate scales for reading in the two different cases; for it is obvious that, without a long vernier arm on the moving weight, to different parts of which the two verniers can be attached, the two zero points of the scales will not coincide, because

the weight of the lever 3 tons, which forms an important and useful factor in the balancing of the moving weight of 2 tons, has its centre of gravity at different distances from the alternative centres. For this reason the machine as here arranged will not read to 25 tons in the more sensitive position, but only to about 20 tons: although it is easy to see that it could readily be made to do so, and for testing specimens of 1 inch diameter this would perhaps be more convenient.

In passing this machine for marine purposes, the Board of Trade tested it carefully, and insisted upon the jockey weight being dismounted and accurately weighed, when it proved to be absolutely correct, and weighed 2 tons to within a fraction of an ounce. The machine was found to turn with less than a 2-oz. weight placed upon the shackle when on the 100-ton centre: that is to say, about 1-2,000,000th of its maximum weight can be recorded, or a range of nearly 2,000,000 can be dealt with. When the 20-ton centre is used, the difference between the tensile strength of No. 12 and No. 16 cotton can be ascertained, the former being rather less than $3\frac{3}{4}$ lbs., and the latter rather more than $3\frac{1}{2}$ lbs. For laboratory purposes the importance cannot be over-estimated of having so sensitive a machine, and at the same time one that can always be verified in a few minutes by putting a standard $\frac{1}{2}$ cwt. on the shackles and hanging a 4 lb. weight at 56 inches from the fulcrum, when the 100-ton centre is in use.

In addition to the ordinary wedge-holders in the shackles, the machine is provided with a set of swivel shackles hanging from spherical seats, to hold dies for screwed specimens and also split dies for cheese-headed specimens. The shearing shackles are of somewhat special form, and are made of cast-steel, fitted with hardened steel dies for specimens of $1\frac{1}{2}$ and 2 inches diameter. The specimens are nicked down to $1\frac{1}{4}$ and $1\frac{3}{4}$ inch diameter respectively, and are sheared in the manner indicated in Fig. 22, Plate 88.

Autographic Force-Strain Recorder.—The machine is fitted with an arrangement devised by Mr. Wicksteed, and shown in Figs. 25 and 26, Plate 90, for obtaining automatically force-strain diagrams.

To the test-piece T, Fig. 26, held in the shackles SS, are attached two clips CC. Hardened steel centres on these clips are pressed, by means of nuts acting through springs, against the specimen T at points which are at an accurately measured distance from each other, usually either 6 or 8 or 10 inches. In the lower clip the end of a copper wire W is held by means of the friction produced by a small weighted lever L. The wire passes over a pulley carried by the upper clip and centred at one end of a wooden rod R; at the other end of the rod it passes over two more pulleys, and thence round the recording barrel B. By this means the barrel with the paper placed upon it is rotated through the distance through which the lower clip becomes further separated from the upper one, that is through the distance through which the specimen elongates between the two points of measurement. By means of suitable gearing the spindle N, to which the handle H is attached, is made to turn with the movement of the jockey weight along the beam; and by means of a worm and worm wheel it actuates the screw E working in a nut in the body of the slider D, which carries the metallic pencil P. Hence the travel of the slider corresponds with the travel of the jockey weight along the beam, and the pencil traces on the paper a line which is an exact measure of the load on the test piece. The combined effect of the two motions—namely the rotation of the barrel on its axis, and the longitudinal travel of the pencil parallel to the axis—results in the production of the characteristic diagram of force and strain. The pencil being on the top surface of the barrel, and held vertically, its weight alone is sufficient to give the necessary mark without the aid of any spring to press it against the paper. There are also a pointer and scale in a convenient position for showing at the same time the position of the beam.

Attention may be called to the arrangement of pulleys shown in Figs. 20 and 21, Plate 88, whereby fast and slow speeds can be conveniently obtained.

Discussion.

Professor HELE-SHAW said that since the paper had been written the circulating arrangement described in page 394 had been subjected to a number of tests, and the length of pipe in the furnace had been shortened to one half of that originally tried. In addition to this alteration a stand-pipe had been added in order to ensure circulation; the water taken from the bottom of the boiler passed up over the top of the stand-pipe, whereby sufficient head was obtained to force it down again to the bottom. There was also a small pipe for the escape of steam from the top of the stand-pipe into the steam space of the boiler, in order to prevent any possible accident. The results of the tests were given in the accompanying Table, and were also plotted in the three diagrams, Figs. 17 to 19, Plate 87. The experiments were made with one thermometer inserted at the bottom of the boiler in a gun-metal pocket filled with oil, and another thermometer placed in another pocket at the surface of the water. In the three diagrams the upper line represented the readings of the upper thermometer, and the lower line those of the lower. The first diagram, Fig. 17, represented the earlier experiments made with the longer circulating pipe, where there was no head of water; and it showed that at the end of five hours there was a difference of nearly 180° between the temperature of the water at the bottom and at the top, the temperature being 300° at the top and 116° at the bottom. The second diagram, Fig. 18, showed the action when the pipe had been shortened; after $3\frac{1}{4}$ hours there was a maximum difference of about 135°, which was an improvement on the previous trial. At the end of $3\frac{1}{2}$ or 4 hours the temperature below suddenly jumped up to within about 20° of that of the upper surface. It seemed a puzzle why the temperature should suddenly increase at the bottom, until it was noticed that at that time a sort of small explosion had taken place in the thick cylinder-oil in the pocket in which the lower thermometer was placed. Turpentine was then substituted for the oil, and as shown in Fig. 19 the result was that the maximum difference of temperature with the circulator in action was only from 60° to 70°, or half of what it had

Results of Experiments with McCulloch's Circulating Pipe.

Temperatures of Boiler Water at Surface and at Bottom.

See Diagrams, Figs. 17 *to* 19, *Plate* 87.

Time.	18 June 1891. Fig. 17. Longer Pipe.		27 July 1891. Fig. 18. Shorter Pipe.		28 July 1891. Fig. 19. Shorter Pipe.	
	Temperature		Temperature		Temperature	
	at Surface.	at Bottom.	at Surface.	at Bottom.	at Surface.	at Bottom.
A.M.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.
10 30	64°	64°	..	..	..	..
10 45	67°	64°	..	..	..	..
11 0	72°	68°	..	..	68°	65°
11 15	73°	68°	76°	70°	68°	64°
11 30	83°	66°	78°	71°	69°	65°
11 45	97°	66°	93°	74°	80°	69°
12 0	120°	68°	105°	75°	96°	73°
12 15	150°	70°	125°	80°	100°	78°
12 30	182°	72°	138°	84°	104°	81°
12 45	204°	74°	157°	89°	114°	87°
1 0	230°	76°	170°	93°	126°	94°
1 15	244°	80°	180°	98°	137°	100°
1 30	260°	86°	188°	102°	150°	107°
1 45	268°	88°	205°	112°	160°	116°
2 0	275°	90°	220°	116°	184°	124°
2 15	287°	92°	248°	125°	200°	133°
2 30	294°	98°	268°	133°	225°	225°
2 45	302°	104°	286°	160°	250°	250°
3 0	305°	102°	302°	279°		
3 15	298°	111°	314°	296°		
3 30	300°	116°				
3 45	302°	121°				
4 0	304°	122°				
4 15	308°	122°				
4 30	309°	123°				

(Professor Hele-Shaw.)

been before; the temperature of the top water was increased at about the same rate as before, and the diagram still showed a sudden rise in the temperature of the bottom water when at the end of $3\frac{1}{2}$ hours the temperature of the two became the same. It was intended to make more experiments with mercury in the pockets in which the thermometers were inserted; but owing to the present pockets being made of gun-metal, mercury could not conveniently be used in them.

In the elevation shown in Fig. 2, Plate 79, the pipe S was the steam-pipe from the boiler to the engine; and the larger pipe E was the exhaust pipe, which was not generally used, but only when working the engine as a high-pressure or non-condensing engine, in which case the steam had to be exhausted direct from the low-pressure cylinder into the chimney. The pipe O was for the discharge of the circulating water into the measuring tank M. The feed-water was taken from the feed-tank D, and was delivered by means of the pipe P into the boiler. The injector was placed against the wall of the stoke-hold.

With the dynamometer brake a great deal of trouble had been experienced in keeping the hollow rim of the fly-wheel water-tight. It had been tried at first to pack it with wood; but it was found that the water came out all over the brake blocks, and interfered seriously with the results. Ultimately cast-iron segments had been used for closing the inner face of the rim with rust joints, packed with rust cement rammed in as hard as possible. This plan he thought had at last succeeded.

In the alternative-centre testing machine it might be asked what happened to the nearer fulcrum when the further fulcrum was brought into action. The bearing of the nearer fulcrum was fixed, and could not be moved out of the way as the other could. The further fulcrum was slightly higher than the nearer, and in ordinary working the rise of the beam was limited by the distance collar D, Fig. 20, Plate 88, which was removed only when the end of the beam had to be let up higher for changing from one fulcrum to the other. When the collar was in its place, the range of the beam's vibration was so limited that even when it went up to the collar the nearer fulcrum did not touch its bearing.

The new shearing arrangement shown in Fig. 22, Plate 88, gave satisfactory results. It used to be found with the ordinary contrivance that the results were unsatisfactory in shearing one side of the specimen irregularly. With the present dies the shearing action was as perfect as it could be. When a shearing test was made of soft material and stopped half-way, the specimen generally looked like a crank: the two ends were left exactly at the same distance apart, and the centre-piece was sheared half out, and the whole of the material seemed to flow together, so that a sort of crank was produced.

Professor WILLIAM RIPPER was greatly pleased to learn from the paper that such excellent arrangements were made for the education of engineers at University College, Liverpool. In regard to the measurement of the steam consumption in the experimental engine, he enquired whether it was the feed supply that was measured, or the condensed steam collected in a separate vessel after passing through the engine: because he had himself always found a considerable difference between the records obtained in these two ways. In the case of an engine designed with such elaborate arrangements as those now described for interchanging the cylinders—using the high-pressure cylinder by itself and exhausting from it direct into the condenser, working as a compound engine with two cylinders only, or working the three cylinders all together—he thought it would be of much interest to engineers to have records of the results of experiments carried out under those different conditions. Although so many valuable tests had already been published in regard to steam-engine economy, he believed among manufacturers there was still a great amount of ignorance and lack of appreciation of the importance of the subject. Marine engineers had necessarily been well aware of the importance of economy; but that was not the case in many of the manufacturing centres. Lancashire was probably at the head of stationary-engine practice in regard to economy; but even in so important a centre of manufacture as Sheffield he doubted whether there were half a dozen compound engines in the whole town. The enormous waste of steam that must be going on in a

(Professor William Ripper.)

place where such a great amount of power was being used was sufficient to show how much there was yet to be learnt by manufacturers in general with regard to the importance of steam economy. He had not himself the advantage of an engine capable of the number of changes which that described in the paper could undergo. With his own experimental engine in Sheffield the consumption could be changed from 22 lbs. weight of steam per horse-power per hour to 40 lbs., by working under different conditions; and the range with the engine now described must be much greater. It would be a matter of great interest to engineers and manufacturers to know that with the same engine such various results could be obtained. If it were said that a marine engine could get one horse-power from $1\frac{1}{2}$ or 2 lbs. of coal per hour, while another kind of engine used 5 lbs. or more, that was not so striking as to show what could be done with the same engine working with the same pressure of steam under different conditions.

Another matter which he was sure engineers would like to know more about in connection with this experimental engine was what results had been obtained from the means here provided of varying the angles of the cranks relatively to one another. It would have been of great interest if the paper had given some record of the results of experiments upon this point.

In regard to the difficulty experienced with the fly-wheel used as a brake, he had a somewhat similar arrangement of brake, but had not had the same difficulty, because his engine exerted only about 40 H.P., and therefore there was not so much power to be taken off the wheel as in the present instance. For experimental purposes in most colleges he thought much less power would answer almost every requirement. It was a good thing however that there were some exceptional colleges having an engine of such a size as that now described, and capable of producing such a variety of results.

Mr. CHARLES COCHRANE, Past-President, presumed the circulating arrangement alluded to in page 394 was a self-circulating arrangement, and that the feed-pump had nothing to do with producing the circulation. In that case he thought the cause of the long delay in

its action, as indicated in the diagrams, Figs. 17 to 19, Plate 87, was not far to seek. The fire being inside the flue, above the bottom of the boiler, was therefore heating the water above the flue. The hot water rose to the surface; and the slowest circulation was that which took place downwards, above and at each side of the flue, where the width of the surface of the water was the greatest. Meanwhile beneath the flue there was the least width of water for the downward circulation to travel through, the width diminishing with reduced depth of water measured upwards from the bottom of the boiler; and though the heat from the fire was so little through the bottom of the flue as to produce little or no effect at all, yet as the smaller volume of water became gradually warmed by the circulating apparatus a point was at length reached at which it would act more rapidly, owing to the diminished volume of water to be warmed; and hence the sudden rise shown in the diagram occurred when the water at the bottom suddenly assumed the temperature of the rest of the boiler. If this were the cause, as he believed it to be, of the sudden rise, it had nothing to do with the oil or the turpentine in which the thermometer was inserted. With the circulating pipe carried through the furnace he thought there must have been a narrow escape from some accident; the pipe had wisely enough been shortened already to half its original length, and he considered it would be better still to sweep it away altogether.

Mr. JAMES PLATT asked at what point the temperature was taken at the bottom of the boiler relatively to the delivery nozzle of the circulating pipe.

Professor HELE-SHAW said the thermometer extended inwards about 6 inches from the front of the boiler, and was about 18 inches from the delivery end of the circulating pipe.

Mr. JAMES PLATT thought in that case the temperature noted could be only that just at the delivery of the pipe, and could not be taken as the mean temperature of the water in the bottom of the boiler throughout its whole length.

Mr. STEPHEN H. TERRY asked whether in the dynamometer brake any allowance had been made for the friction of the two glands in the central stuffing-box; and if so, what was the amount of the allowance in estimating the effective load lifted by the brake. With regard to the experimental engine and its economy of fuel, in steam ships the great point was not merely how economical the engine was by itself, but how economical the machinery was as a whole, including also the boiler, the condenser, the feed heater, and the rest of the apparatus. With the experimental marine engine now described was associated a marine boiler of good design; but nothing had been said about any provision for testing the economy of the boiler as a producer of steam, apart from the engine. There was still a great deal to be done in economy in regard to the marine engine, and a good deal also to be done by making the boilers produce more steam for a given weight of coal. This was a point which could not be lost sight of in a technical college; and it was therefore desirable that tests should be made on combustion and on steam production, in addition to those on the modes of using the steam when raised.

Mr. HENRY LAWRENCE asked what was the size of the circulating pipe added in the boiler furnace; and whether it was made of wrought-iron or copper. Also what kind of wood was used for the 150 blocks which were attached to the strap of the brake wheel.

Professor J. A. EWING, in congratulating the author on the success which he had attained in establishing an engineering laboratory in Liverpool, said it was hardly possible that the congratulation should not be mingled with an almost envious admiration on the part of other professors of engineering in the country, especially in regard to the diplomacy which had so well succeeded in stimulating the generosity of Sir Andrew Walker to provide the requisite funds for the purpose. This was a matter which appealed to himself with peculiar force at the present time, because in Cambridge, where he had just begun to work, they were anxious to establish a large engineering laboratory, and the first

thing to be considered was where to obtain the necessary means; they were in fact waiting for a millionaire.

With regard to the engine itself, it was impossible not to notice that in every successive engineering laboratory the experimental engine was becoming more and more expensive and complicated. The policy he thought was somewhat doubtful of presenting to students, who had necessarily but little previous acquaintance with steam practice, such a complicated piece of mechanism as an experimental engine of this kind. With a view to research also, might it not be questioned whether an engine which was capable of such a variety of transformations was after all the best means of comparing the efficiency of various modes of working the steam engine? As a triple-expansion marine engine it was no doubt designed to be as efficient as possible. Was it then fair to take the results which would be got from it when it was worked simply compound with two cylinders only, or worked as a single engine, and to compare these as representative examples of compound or single-cylinder working? He questioned whether the desire to work the engine in an extensive variety of possible ways might not be carried too far. Even for the purposes of research, it might be unable to do justice to each of the different modes of working. Probably with little increase of cost several separate engines might be provided for a laboratory, each of which should be a fair representative of its own manner of working.

With regard to the dynamometer brake, with which it had been mentioned that some difficulty had been experienced, he was somewhat surprised that the beautiful hydraulic or turbine brake had not been adopted, which had been applied by Professor Reynolds to the engines in the Whitworth laboratory at Owens College, Manchester. It would be difficult to imagine anything more perfect than that brake was; and failing its use, surely the next best brake was the plain rope-brake. No engineer, he thought, who had worked with a rope-brake had failed to appreciate its value highly; and he considered it was much to be preferred to a wood-block brake. The difficulty which had been met with in working with water, and in keeping the hollow rim of the fly-wheel water-tight, might have

(Professor J. A. Ewing.)

been avoided by not attempting to make the rim water-tight, that is, by not closing the rim at all on the inside, but merely having an open gutter in the rim which could be kept full of water by the centrifugal force: a little splashing of the water would not have mattered with a rope brake. The speed of the fly-wheel was such that with an open gutter in the rim the water stood in it; and the only inconvenience was that, when the engine was stopping, a certain critical velocity was reached at which all the water came down. But that was a beautiful illustration of the principle of centrifugal force which was much appreciated by students. He joined Professor Ripper in the hope that some account would be given of what the actual performance of the experimental engine was, with some indicator diagrams, if not actual tests of efficiency. Such tests need not take a long time to make. This was a point which was not so generally appreciated as it might be. With the compound engine of the marine type which he had had in the engineering laboratory at University College, Dundee, which was provided with a surface condenser, he had found that it was possible to get a trustworthy test of the performance of the engine in ten minutes. Not that any one could go into the laboratory, and in ten minutes obtain the result: the engine had to be kept working under the intended conditions for an hour or two before the test was made; but the actual observation need not take more than ten minutes. The principle of course was to examine the amount of heat supplied to the engine and passing through it, by measuring the weight and temperature of the condensed water from the surface condenser. An engine developing 40 or 50 I.H.P., and running about ten minutes, would collect from 100 lbs. to 200 lbs. of condensed water, which was a quantity quite sufficient to collect and weigh; and by taking such tests over and over again at short intervals, it was found that they agreed with one another closely. Any variations in the conditions of running could in that way have their effects examined with great rapidity; and in fact in a single day the engine could be tested under various conditions of jacketing and non-jacketing, and with various grades of expansion.

With regard to the autographic recorder of the testing machine, an identical recorder had been fitted by Mr. Wicksteed two years ago to the experimental testing machine in Dundee, and it worked most admirably. One point that had not been alluded to was the manner in which the cord rotating the barrel was released at the moment of rupture of the specimen. In the Dundee machine the cord terminated in a short piece of copper wire, which was clutched by the tail of a little horizontal weighted hammer at the lower of the two clamps on the specimen. When the specimen broke, the lower holder carrying the hammer came down suddenly through a short distance with great speed; and the inertia of the horizontal weighted hammer threw its tail up and released the wire, and the barrel ceased to be rotated. This autographic recorder he had found to be exceedingly perfect, subject of course to the qualification that the accuracy of the results depended upon the steadiness with which the operator worked the jockey weight along the lever. It must not be allowed to run spasmodically by fits and starts, or to run out so far as to bring the lever end down upon the lower stop. No doubt in testing a specimen which had a sharply defined point of rupture it was difficult to get the diagram to represent fairly what was happening in the specimen; but with proper care it might be done, and when it was done nothing could be better than that method of obtaining in an autographic diagram the relation of the strain to the stress. It was not too much to say that, when fitted with such an autographic recorder, and when also supplied with a hydraulic intensifier, which he was surprised to find had not been provided in the present instance, nothing could exceed in point of accuracy and convenience the single-lever testing machine designed by Mr. Wicksteed.

Mr. DAVID JOY said that, as his form of radial valve-gear had been adopted on the intermediate cylinder of the experimental engine, he might be excused for saying a word in favour of radial gears. He had had much pleasure in devoting considerable attention to the designing of this valve-gear, because it had a bearing on the education of the more advanced engineering students, teaching them something of what was going forwards in regard to valve-motions.

(Mr. David Joy.)

It had been objected to the radial valve-gear now coming so much into use that the link gear still held its own and would continue to do so, because the men in the engine room having had to use it so long could understand it, while they could not understand the more modern and scientific radial gear. But if advances and improvements were to be allowed to be retarded by want of education on the part of workmen, it was surely a pressing duty to raise the education of the workmen. He had recently met an engine-driver, who was second engineer on board a ship fitted with his own radial valve-gear. Finding him an intelligent man who looked well after the machinery, he sent him a complete set of drawings of the gear, with rules for its construction, in order that he might be able to study it thoroughly and make himself fully acquainted with its construction and working. Within a few months he had the gratification of hearing from him that the drawings had proved more serviceable to him than anything else that could have been sent to him, because the information he had derived from them had enabled him to pass an examination which gave him a higher grade as an engineer. Rather therefore than let the improvement of machinery be retarded by the want of education of the men, it was a foremost duty to bring the men up to the advancements that were being made. It had been urged against the radial valve-gear that it would not do for high speeds: he maintained that it would. It was said that it yielded by the springing of the parts in working, and that what appeared to be the distribution, according to the valve-path diagram and the setting of the valve, was not what was actually obtained in the cylinder when the engine was at work. When properly designed his own valve-gear would not give in the least; there was no bend or spring at all. With high-speed engines he avoided increasing the weights for the purpose of increasing the strengths of the parts; indeed the weights had really been reduced and the valve-gear made lighter by arranging all the material in the direction of the work to be done. All the levers were made almost like saw blades, that is very narrow and deep, thereby giving the strength in the direction of the strains; and the result was that the indicator diagrams came out clean and sharp, and as full as

could be desired: showing that the engine was not running with a yielding valve-gear, but that all the parts were strong enough to prevent bending or springing of any kind.

Mr. EDWARD REYNOLDS said that, so far as the experimental engine had been described, it appeared to him to be exactly what was wanted for the education of engineering students.

Some members like himself, though not practising specially as marine engineers, were nevertheless able to obtain particulars of the consumption of fuel &c. in some of the most important fleets in the world; and certain apparent anomalies existed which were well worth investigation. For example he knew of ships in which the consumption was 2·1 lbs. of coal per I.H.P. per hour, running at high speeds and working with less coal in proportion to their carrying power multiplied by their speed cubed than some of those fitted with more highly expansive engines. Such a result was of course open to explanation in many ways which this experimental marine engine was well calculated to illustrate, because, as he understood the paper, the experiments made with it were directed amongst other things to ascertaining the effects of extreme expansion, or what some engineers would agree with himself in calling over-expansion.

Although it was described as an experimental marine engine, he thought some of the circumstances forming the chief distinction between marine and other engines had been missed. For example the experimental engine had a fly-wheel applied to it, whereby certain variations in the power exerted were overcome in a way in which they were not overcome at sea. If instead of to a fly-wheel the power could be applied to a screw propeller acting on a yielding medium like water, there would be certain irregularities of action, to which some importance was to be attached. For example, it had been claimed by Mr. A. E. Seaton that he had attained in practice higher results from engines making more equal effort on the water; while another eminent engineer did not believe this would make any appreciable difference in efficiency. Certainly the coal accounts of ships with equally working engines showed good results; and, so far

(Mr. Edward Reynolds.)
as he had himself been able to observe, the disappointment in certain cases of triple expansion had been largely due to the fact that the engines were not sufficiently hard worked. They were not like the "Majestic," which the members had had the pleasure of visiting yesterday, where the boilers were fully kept up to the mark, with plenty of steam so as always to have proper pressure in the third cylinder. Attention had yesterday been drawn by Mr. White (page 349) to the important practical bearing of this point.

Another matter in which he was specially interested arose out of this question of unequal action, though it did not altogether come under collegiate observation: namely that the crank of the high-pressure cylinder, having to do more than its fair share of the work, caused unequal wear of the bearings, and the shaft ultimately came to grief. But his chief object was to call attention to the fact that the experimental engine would have more value if arranged to work against a yielding medium, instead of being fitted with a fly-wheel as at present. Probably the most convenient way to attain this object would be to drive a centrifugal pump with the inlet and outlet opening into such large chambers that there would not be any such momentum of the water column as might exist in long pipes.

Professor ARNOLD LUPTON considered one of the advantages of the experimental engine was that it would give the means of ascertaining the steam consumption per brake horse-power for a single cylinder and for a compound engine, with all the friction of the three cylinders and valves and air-pump, which he thought would afford a practical comparison of much value. With regard to the boiler, he enquired whether in the absence of the circulating arrangement it was expected that the bottom would always remain cold, say not hotter than 180° F.; and if so, whether the gases could then be delivered into the chimney at a lower temperature, thereby ensuring a higher theoretical economy of coal consumption. If the boiler could always be kept hot at the top and cold at the bottom, it seemed to introduce a possibility of low flue-temperatures which was not always contemplated in practice. It would be like making the boiler its own feed-water heater or economiser, an arrangement only

practicable perhaps where there was a superfluity of boiler space. The magnificent testing machine and the rest of the arrangements described in the paper inspired the hope that the individual munificence to which they were here due would be emulated, if not by individuals, at any rate by communities, for furnishing other engineering colleges with similar or possibly still more extensive laboratories.

Professor JOHN GOODMAN mentioned that last summer he had visited several of the technical colleges in the United States, and had expected to find them excelling in respect of testing appliances; but he had seen nothing whatever that could compare with the machinery in the Walker engineering laboratories. Most of the American laboratories were fitted up with inferior experimental engines; in fact there was only one experimental engine that he knew of in the United States which would compare with that described in the present paper: it was at the Massachusetts Institute of Technology in Boston. It was fitted with Corliss valve-gear; and he thought that, if the experimental engines in this country were arranged to have one at least of their cylinders fitted with that valve-gear, it would be useful for the instruction of the students.

In regard to the loss referred to by Professor Ripper (page 401) between the feed water and the water discharged from the air pump, this had been more or less of a mystery for a long time. The loss he believed was always found to be at least 5 per cent., and he had himself actually noted as much as 15 per cent., between the feed water put into the boiler and the water discharged from the air pump; and it was not known exactly where the loss occurred, though some of it was certainly due to leakage from the glands.

Besides learning the different methods of working steam-engines so as to get different degrees of economy, it was also important that students should be taught how to set the valves. In all experimental laboratories he should like to see a separate engine so arranged that the valves could be erroneously set, and that the angles of the eccentrics could be set wrong, and the length of the valve rods elongated and shortened. The students should then take diagrams

(Professor John Goodman.)

from the engine, and determine from the diagrams what was the defect and how it was to be rectified. In testing engines and taking indicator diagrams from them, engineers frequently obtained peculiar diagrams, the solution of which was sometimes to a great extent pure guesswork. If those peculiar diagrams were taken in a laboratory where there was the means of readily finding out what was the actual cause of the peculiarity, the experience so gained would be of great value to the students. It would also be useful to try leaky valves and leaky pistons; and to circulate different quantities of steam through the jackets, and to have them sometimes full of water, as was often the case in actual practice.

As marine engines worked without governors, he enquired whether the experimental engine was fitted with any governor. The boiler shown in Figs. 13 and 14, Plate 85, appeared to be small for a 150-H.P. engine; and he should be glad to know whether any auxiliary boiler was used, from which additional steam was obtained.

The alternative-centre testing machine he considered an excellent arrangement. It had been looked upon as a weak point in connection with the Wicksteed machine that the travel of the jockey weight was so small when testing small specimens; and this arrangement of the alternative further centre got over that objection in an admirable way. With regard to the autographic recorder, he had a strong objection to any autographic gear which depended upon the skill of the operator, and he considered it ought to be entirely independent of any manipulation. In testing certain specimens—for example gun-metal or steel at high temperatures, and many other tests where the specimen did not elongate regularly—it was absolutely impossible, however slowly the machine was worked, to keep the steel-yard floating when the jockey weight was being travelled by hand. An autographic gear working on that principle would not show how the metal actually behaved under the test; whereas such an arrangement as Mr. Wicksteed's or Professor Kennedy's gave an exact record of how the specimens behaved. The shearing shackle he was glad to hear was found to be so successful, for he believed he had originally proposed it to Mr. Wicksteed.

Mr. GEORGE CAWLEY enquired whether the jockey weight on the testing machine could be travelled along the beam by the engine at various definite speeds, and whether this could be done by cone pulleys or other means. With regard to the alternative centres, which had been referred to in the paper (page 394) as the chief feature of the machine, and one that was entirely novel, he mentioned that in a testing machine which he had made about sixteen years ago for the Imperial College of Engineering, Tokio, Japan, alternative centres were used. The same machine also had connected with it an autographic recording apparatus, which gave excellent diagrams without any manipulation by the experimenter; a varying-speed arrangement for moving the jockey weight along the beam; and a trigger device, similar to that used in the present machine, for indicating the exact position of the jockey weight on the beam when the specimen broke. A description of the principal details of that machine had been given in *Engineering* (16 November 1877, page 386).

Mr. SAMUEL BOSWELL noticed that in the construction of the boiler the longitudinal seam was placed down in the water space, instead of above the water line as he believed was considered preferable in modern practice. He asked whether there was any arrangement for altering the length of the fire-grate, or raising or lowering the fire-bridge, so as to get results under different conditions. Although he had seen much of the single-lever testing machine, he had had more experience with one of Mr. Kirkaldy's machines made by Messrs. Greenwood and Batley, which he preferred. In a Kirkaldy machine at Messrs. Galloways, which he had recently adjusted for the Board of Trade, the balance was turned by even less than an ounce in a scale pan attached to the short end of the L lever; and he had found that many engineers could hardly believe this could be done either in the single-lever machine or in any other.

Mr. JAMES M. MCCULLOCH said he had himself had some experience with the boiler circulator described in the paper; and if it was not

(Mr. James M. McCulloch.)

safe to put the circulating pipe in the fire, it was not safe to use the water-tube boilers which were now being constructed entirely of small water-tubes. In the present instance the circulating pipe had three connections open to the boiler; and if the pipe were to burst it would simply put the fire out, while the three connections could all be closed, and then the boiler could go on as if the pipe were not there at all. The length of the pipe depended upon the length of the furnace and the force of the draught; in the present instance there was a strong draught. The pocket in which the thermometer was inserted in the bottom of the boiler was unfortunately nearer the delivery end of the pipe than he wished; but it had been so fixed before the delivery was arranged for. The third diagram, Fig. 19, Plate 87, represented a period of $3\frac{3}{4}$ hours, during which 2 inches of cold feed-water was run into the boiler without producing any appreciable effect upon the temperature of the water in the boiler. Having been connected with boilers and their repairs for the last thirty years, he had found that the repairs of marine boilers were almost entirely at the bottom; and he regarded it as a reflection upon engineering that the bottoms of boilers should be in the condition in which all who had had any extensive experience in the survey of marine boilers would agree that they frequently were at the present time on board ship, owing as he believed to want of circulation. The boiler he considered was the most vital part on board a steamer, and most wanted attending to.

Professor HELE-SHAW said it was only right towards the munificent founder of the Walker Engineering Laboratories to mention that no diplomacy had been required for inducing him to provide them for the benefit of Liverpool. Having originally promised £15,000 for the purpose, he had ultimately defrayed without hesitation their entire cost, amounting to £23,000.

If the seeming complication of the experimental marine engine were objected to (page 405), it might be explained that there were also other engines in the laboratory, including a 40-H.P. Robey engine, all of which were simple and direct-acting; and ordinary indicator diagrams could be taken from any of these by the less

advanced students. Moreover as a fair proportion of the fifty students employed their leisure time in the workshop in making for themselves steam engines from 1-3rd H.P. to 5 H.P., there were always quite enough of the ordinary kind of steam engines to make experiments upon. The experimental marine engine was fitted with a high-speed Porter governor (page 412) of the ordinary kind, acting directly upon the throttle-valve.

The criticism by Mr. Reynolds in regard to the fly-wheel (page 409) was quite a fair one; to that extent the experimental engine did not exactly represent an actual marine engine. In the absence of a screw, the difficulty was to manage without a fly-wheel. There was however the means of removing the fly-wheel by the aid of a travelling crane; and possibly at a future date an experiment might be made with a screw working in a tank of water.

He desired to thank Mr. Joy for his kindness in allowing the use of his valve-gear, and for all the trouble he had taken in adapting it to the experimental engine; and also the engineering Committee of the College, and the other engineers who had been asked to give any assistance, all of whom had agreed in regarding the laboratory as a collection of engineering appliances for educational purposes, and had been most kind in doing all they could towards the promotion of that object. He would also take this opportunity of acknowledging the assistance he had received from Mr. John Reney Smith, formerly chief draughtsman of Messrs. Forrester and Co. On some future occasion he hoped to present the results asked for by Professor Ripper (page 401) from the different modes of working the experimental engine.

There had been no means of measuring the friction of the glands in the central stuffing-box of the dynamometer brake (page 404); no doubt there was some friction, but it must be a very small amount. It must not be overlooked that in the working parts of the engine there was always a large amount of friction, which was ascertained by subtracting the brake horse-power from the indicated horse-power; and the gland friction would thus be taken account of with the other constant resistances. The wood used for the blocks round the brake wheel (page 404) was varnished deal. The hydraulic or turbine

(Professor Hele-Shaw.)

brake (page 405) he regarded as a beautiful contrivance, but it was expensive, and he had thought at first that the brake now adopted would be cheaper. The open gutter of water in the rim of the brake wheel (page 406) had been tried; and although it did illustrate the principles of centrifugal force and of gravity, it was objectionable to have the floor and neighbouring machines splashed with water whenever the brake wheel was stopped; moreover as previously mentioned water on the surface of the brake blocks had been found to be decidedly objectionable. That was why it had been found necessary to close the rim.

For testing the economy of the boiler (page 404) apart from the engine there was no special means at present, other than with ordinary experimental engines. Any desired alteration could be made in the bridge or in the length of the fire-grate (page 413).

The heating effect of the circulating pipe was proved not merely by the thermometer readings, but by holding the hand against the end plate of the boiler at the bottom. In the absence of the circulator, this could be done for a long time after the fire had been lighted; but since the addition of the circulator, the end plate became too hot to do so after the boiler had been at work for a comparatively short time. The circulating pipe was of iron inside the boiler, and of copper outside.

The autographic recorder of the testing machine recorded automatically the motion of the jockey weight (page 412); and although this might not be done with absolute perfection, it was done to a degree of accuracy far in excess of any possible error from this cause which could be detected on the autographic record. There was a simple practical way of controlling the speed of travel of the jockey weight by means of the hand-wheel H, Fig. 20, Plate 88; the pressure of the hand on the rim of the wheel acted as a brake for retarding the travel; or the speed could be increased by pushing the driving strap further upon its pulley. At the same time there was also means of adjusting the speed of the ram straining the specimen. By these two methods in combination the speed of testing a specimen could be regulated through any range found desirable.

The PRESIDENT was sure the Members would all agree with him in presenting a vote of thanks to Professor Hele-Shaw for his paper. A large number of engineering laboratories were now at work, and he was glad that it was so. In former years young engineers had had few opportunities of studying except under the hard rule of practice; and future engineers were to be congratulated on the facilities for study now placed within their reach. It could not be expected however that all the professors who undertook to teach them would agree in everything; if they did, it would not be of much advantage in the way of progress. Some diversity of opinion among them would certainly do no harm to the engineering laboratories of the country.

ON THE MECHANICAL APPLIANCES EMPLOYED IN THE CONSTRUCTION OF THE MANCHESTER SHIP CANAL.

By Mr. E. LEADER WILLIAMS, Engineer in Chief.

Magnitude of Work.—The Manchester Ship Canal, Figs. 1 and 2, Plates 91 and 92, is the largest work of its class in this country; and the Mechanical Appliances used in its construction have been on the largest possible scale, in order to minimise the employment of labour and to hasten the completion of the work. The number of men and boys employed on the Canal has never exceeded 17,000; and about 200 horses have been used. As the excavation amounts to 46½ million cubic yards, of which over 10 millions are sandstone rock, it is clear that any available number of men and horses would be insufficient to do the work in any reasonable time. Ninety-seven steam excavators and eight steam dredgers of large power have therefore been employed. The spoil excavated has in most cases had to be taken several miles to the spoil grounds, the position of which has necessarily been selected where land was moderate in price. For this work and for the general purposes of construction 173 locomotives and 6,300 trucks and wagons have been used.

Railway.—A railway of the ordinary 4 ft. 8½ ins. gauge has been laid along the whole course of the canal, in many places on both sides, with numerous sidings. These lines, with those laid in the bed of the canal for excavating purposes, amount to a length of 228 miles of single line. Flat-bottomed steel rails, 56 lbs. to the yard, with fish joints, are laid on ordinary cross timber sleepers. The cost was about £630 per mile of single line. The railway and its rolling stock are on a larger scale than some of the passenger and goods lines worked in this country or on the continent.

Rate of Excavation.—The rate of excavation has varied from $\frac{3}{4}$ million to $1\frac{1}{4}$ million cubic yards per month. As the work proceeded and the cuttings became deeper and the inclines steeper, and as the sandstone rock required blasting before the excavators could remove it, the rate of excavation in the bottom of the canal is slower. The wagons are hauled out of the bottom of the cuttings by locomotive power, the gradients adopted being generally 1 in 30. Steam cranes were largely used in rock cuttings, and for setting the masonry. There are employed on the works 124 steam cranes, 192 portable and other steam engines, and 212 steam pumps of various sizes, some being large Cornish pumps that had been brought from the Severn tunnel works. The large plant used consumed about 10,000 tons of coal per month.

Preparation.—As soon as the late Mr. T. A. Walker had got possession of the land as the contractor, he showed great energy in commencing to erect huts, hospitals, and chapels for the workmen; and much honour is due to him and his agents and engineers, not only for the way in which the work has been pushed forward, but also for the care taken for the comfort and welfare of the men. The greater part of the plant was specially constructed for the work; the remainder was principally brought from Mr. Walker's contracts at the Severn Tunnel, and Preston and Barry Dock works. The total cost amounted to £943,610; the whole plant, huts &c. are the property of the Ship Canal Company.

Excavators.—The steam excavators are of several types, some being land dredgers working with a chain of buckets; also Ruston and Proctor's steam navvies, and Wilson's and Whitakers' steam excavators, which all work a single large bucket; and Priestman's and other grabs.

Ruston and Proctor's Steam Navvy.—No less than fifty-eight of these steam navvies are used, being the largest number ever employed on any work. The machine, shown in Figs. 3 to 5, Plates 93 and 94, was fully described in Mr. Ruston's paper at the Lincoln Meeting of

this Institution in 1885 (Proceedings, page 349). Since then the machinery has been improved and strengthened; and it is now a very perfect excavator for almost every description of soil. Its power in removing hard material is greater than that of any other machine yet constructed; soft sandstone rock is removed by it without blasting, powder being required only in hard rock. The buckets for sand excavation on the canal have been increased in size to hold $2\frac{1}{4}$ cubic yards, Figs. 4 and 5, so that two buckets are sufficient to fill a large earth wagon holding $4\frac{1}{2}$ cubic yards. The advantage of this excavator being self-propelled is considerable; but its weight is great, and on very soft ground it requires heavy timbers under the rails. It should be put to work if possible with a high feed, 12 to 15 feet, depending on the nature of the soil; and it will clear its own road, and also that required for the line of earth wagons. The cost is about £1,200. With this machine about 2,000 cubic yards have been excavated in one day of ten hours in good material. A fair average however may be considered to be 600 to 700 cubic yards per day of ten hours. The working expenses of a steam navvy, including wages, may be put at about 30*s.* per day, or 0·55*d.* per cubic yard excavated. Its disadvantages are that its capability is limited to cutting its way forwards only; and that its great weight has sometimes caused its disuse on the canal works, where the ground has been very soft; no ordinary system of rails and sleepers is sufficient to carry the navvy on very soft ground. The fact that these steam navvies can work in hard material is a great advantage, and they have been used in cuttings where no other excavating machine would work.

Wilson's Excavator.—The Wilson steam excavator, Fig. 6, Plate 95, is of the same type as Ruston and Proctor's. It is made by the firm of Messrs. John H. Wilson and Co., of Liverpool, and has done good work on the canal. It is comparatively light, and is therefore easily moved; it can perform a complete revolution round its centre, and thus can work either way, cut out corners, dress slopes &c., in a better manner than the ordinary steam navvy. Its average work may be taken at

600 cubic yards per day of ten hours; occasionally it has largely exceeded this quantity when working in favourable soil. The cost is about £1,050; and the working expenses may be taken at about 25*s.* per day, or 0·50*d.* per cubic yard excavated.

Whitakers' Excavator.—Another of the jib and bucket type of steam excavator used on the works is constructed by Messrs. Whitaker Brothers, of Horsforth near Leeds. It is similar in most of its details to the Wilson excavator, but its cost does not exceed £800; the working expenses may be taken at 25*s.* per day, and the average work done at 400 cubic yards per day of ten hours, or 0·75*d.* per cubic yard excavated.

Grabs.—The Priestman grab and others have been used principally for excavating foundations and other similar work. In suitable soil it has been found to work up to an average of 300 cubic yards per day of ten hours. The difficulty of getting this class of machine to enter hard or dense ground militates much against its use on large works. Its special advantage consists in its working under water from a higher level.

The Wilson, Whitaker, and Priestman excavators have one great advantage over others. They are reasonably light, and the steam cranes that work them are available for general work when the buckets or grabs are removed.

French and German Land Dredgers.—In addition to the foregoing machines, four excavators, constructed by Messrs. J. Boulet and Co., of Paris, have been employed, Figs. 7 and 8, Plate 96; and three somewhat similar ones made at Lübeck, Fig. 13, Plate 98. On the canal works the three latter are known as the "German" and the four others as the "Frenchman" excavators. These seven machines are of the bucket-ladder kind; they are indeed land dredgers, differing from the floating dredger in the fact that the cutting edge of the buckets when in the act of cutting is always towards the machine, that is, the bucket cuts inwards; whereas in the floating dredger the cutting edge is always turned away from the machine

at the moment of cutting. As shown in Figs. 10 to 12, and 14 to 17, the buckets have no bottom to them, that is, the side next to the chains is left open; and when passing over the top tumbler they discharge their contents upon the shoot below, as shown in Fig. 9, Plate 97.

The first cost of the "Frenchman," Plate 96, is about £2,400; and under favourable circumstances it is competent to remove a great amount of material. The best day's performances on the different sections of the canal are as follows:—No. 3 section, 1,943 cubic yards; No. 5 section, 1,624; No. 7 section, 2,250; No. 8 section, 2,025 cubic yards. These are remarkable figures; but the soil and other circumstances must be suitable in order to afford such results. The average day's work on all the districts is about 1,500 cubic yards. If 440 wagons, containing 1,650 cubic yards, were filled per day on No. 8 section by the "Frenchman," it was considered a fair day's work. A bonus of a penny per cubic yard was paid to the men on everything above this quantity. For the excavation of this quantity of material the average daily expenses of the machine in wages of crew, coal, stores, and repairs, the last item being heavy, were about 60*s.*, or 0·44*d.* per cubic yard excavated. There were employed upon the excavator an engine-driver and a stoker, and round it a number of men varying from 28 to 43, the average number being 35; the roads required frequent moving. A special locomotive is required in attendance upon the excavator; for though it is traversed by its own power over the train of wagons it is filling, its movement is not sufficiently rapid. The wagons are also kept in motion in the opposite direction by the attendant locomotive.

A great disadvantage in the use of these land dredgers is their necessarily great weight, amounting to at least 80 tons; they consequently entail a heavy and expensive road, which must be maintained if they are to travel at all. They travel on steel rails weighing 80 lbs. per yard, carried by cross sleepers spaced about two feet apart. When the ground is at all soft, these cross sleepers are again carried on longitudinals. There is nevertheless a constant danger of the machine upsetting into the cutting, as has actually happened once or twice when working in the light marsh clays. On

the other hand there is a decided advantage in the fact that the excavator delivers the spoil at a level of 5 or 6 feet above the surface of the ground, instead of merely at that height above the bottom of the cutting, thus saving time and power in haulage up inclines from the cuttings.

It is only in certain materials and under special conditions that economical work can be got out of this excavator. The materials with which it is competent to deal satisfactorily are sand, loam, gravel, or other light soils. In rock however soft it will not work, and hard clays it cannot touch; boulders or imbedded trunks or branches of trees are also found to be insurmountable obstacles. It requires no turning round when it reaches the end of its allotted cutting; it is only necessary to slew the roads, and it cuts its way back to the starting point. It is just as well that this is so, for the taking down of the machine and its re-erection at another site, even though only at the opposite side of the same cutting, is an operation requiring the aid of a large crane, and a considerable gang of men.

German Land Dredger.—The land dredger known as the "German," Plate 98, is made by the Lübecker Maschinenbau-Gesellschaft, Lübeck. The differences between the German and the Frenchman are slight, and of minor importance, except in one or two particulars. One point of advantage in the German is the wider base given to the machine, enabling the wagons to pass through its centre and receive their load by means of a hopper above, instead of passing at the back and being loaded through a shoot as in the Frenchman. The wider base is of assistance in throwing the centre of gravity farther from the edge of the slope, and therefore in preserving the stability of the excavator. As a matter of fact the author is not aware of any instance in which a German excavator has been tipped into the cutting. Its traversing power is sufficient to move ahead with speed enough to fill the set of wagons standing underneath it, without their having to be moved; hence the attendant locomotive of the French excavator is unnecessary. The best day's performances that are recorded in its favour are as follows:—No. 3 section, 2,073 cubic yards; No. 4 section, 1,736; No. 5 section, 1,725; and No. 6 section,

2,400 cubic yards. The average day's work is 1,416 cubic yards, with an average number of 36 men. The average daily expenses of the machine in wages of crew, coal, stores, and repairs, are about 60*s*., or 0·50*d*. per cubic yard excavated, which is increased to 1·60*d*. per cubic yard by the wages of the labourers who attend on the excavator. The machine weighs about 70 tons, being lighter than the Frenchman, and generally less substantially built; its first cost is the same, namely about £2,400. In other respects the observations already made in regard to the Frenchman apply equally to the German.

The heavily timbered roads required for working the German and French land-dredging excavators increase the cost of working; and as the first cost of these machines is heavy, the cost of excavation does not fall much below the rate of steam navvies, which may be taken in average soils to be 2*d*. per cubic yard, while that of the grabs may be taken at 3*d*., and that of the land-dredging excavators at 1½*d*. per cubic yard.

One peculiarity of the excavation has been the employment of a large number of side-tip wagons, capable of holding 4½ cubic yards each.

Summary of Results.—Summarising the results of experience in the working of land dredgers in England, it may be said that in light material and on level ground they will fill wagons at considerable speed and with economy; and where large excavations of soft material have to be made with rapidity, the bucket-dredging system gives the cheapest and best results. But they will not excavate heavy or strong material; they are difficult and expensive to maintain, and therefore cause delay to the work; they require a costly and a heavy road, and special precautions on soft ground to prevent them from tilting over into the cutting; and they are expensive to move from one cutting to another.

Floating Dredgers.—The Ship Canal Company also own four powerful steam dredgers. The "Manchester" is a hopper dredger, built by Messrs. W. Simons and Co., of Renfrew, and has double

screws at each end of the vessel so that it can steam either way, thus avoiding the necessity of turning in the canal. It can dredge 800 tons per hour in favourable material. The "Mersey" and "Irwell" dredgers were built by Messrs. Fleming and Ferguson, of Paisley, in the bed of the canal between Manchester and Warrington. They each dredge 400 tons per hour into hopper barges. The Barry dredger also delivers into hopper barges. There are also working on the canal four other large dredgers hired from Preston, Ayr, Dumbarton, and the Weaver Navigation; besides smaller dredgers, grabs, &c., worked on barges.

Pile Driving.—At Ellesmere Port there is an embankment faced with stone, one mile long, across an enlargement of the estuary. On each side of the foot of this embankment close timber piling is driven, consisting of pine piles 13 to 14 inches square and 35 feet long. Over 13,000 of these piles have been driven through sand without any trouble, by the use of the water-jet principle. Four steam-pumps were used, which delivered the water at a pressure of about 30 lbs. per square inch through 2-inch india-rubber pipes to the pile, where it was attached to a 1½-inch wrought-iron pipe which was put down under water-pressure alongside the pile. With this assistance the steam pile-engines quickly drove the pile, which without the disturbance caused by the water-jets in the sand could not be driven. Steam pile-engines are employed on various sections of the work.

Mr. E. LEADER WILLIAMS said that not one of the machines mentioned in the paper had been invented by himself, and he had therefore no interest in advocating one more than another. The late Mr. Walker, with his great experience in the Severn Tunnel and many other large works, had been an admirable judge of the best class of machinery to use in such a work as the ship canal; and he

(Mr. E. Leader Williams.)
had been wise enough to see that, with such a variety of soil and so many varying circumstances, the employment of one class of machine alone was hardly the right method to adopt. Therefore while Ruston and Proctor's well-known steam navvy was the main tool used, of which as many as fifty-eight were employed, there were also soft cuttings and light alluvial soil and sand to be dealt with, for which Mr. Walker's energy had led him to bring into use the continental machines known as the Lübecker and the Frenchman. Both of these were land dredgers. The Frenchman discharged the material from the top of the machine to the line of railway outside; the Lübecker traversed over the line of wagons and filled them as it went on. Years ago, before he had the honour of being elected a Member of this Institution, he little thought that in days to come he should have to depend so much upon mechanical appliances in carrying out a great work like the ship canal. It was interesting to him as a civil engineer to notice how in the very commencement of any great work of construction, as well as in carrying it out afterwards, it was necessary to have recourse so largely to mechanical engineering. The ship canal, if it had had to depend upon manual labour, would never have been carried out. The mere loss of interest on capital during construction was so great, that everything possible had to be done to push the work forward in the most rapid manner. The difficulties encountered were the very things which it was the engineer's triumph to surmount. Upon this great work every man who had offered himself had been employed; from 16,000 to 17,000 was the largest number ever engaged, but more could have been employed if they had been forthcoming. Therefore it could not be said in this case that the employment of such a great quantity of machinery had in any way interfered with labour: in fact, but for the machinery, there would have been no employment of labour, because the work could not have been carried out in any reasonable time.

The PRESIDENT said the author had had a great deal of experience in connection with the late Mr. Walker, and no doubt had taken the best means of getting so large an amount of material

removed with the greatest expedition and at the least possible cost. He therefore thought it would hardly be necessary to discuss the interesting paper now read, which would constitute in the Institution Proceedings a valuable record of the difficulties there had been to contend with in this great work and how they had been overcome. He proposed a hearty vote of thanks to Mr. Leader Williams for his paper, which would enable the members all the more to enjoy the visit they were about to make to the canal works through his kind invitation.

EXCURSIONS.*

On TUESDAY AFTERNOON, 28th July, two alternative Visits were made.

After luncheon at the Grand Hotel by invitation of the Local Committee, a visit was made by special free train to the Alexandra Grain Warehouse, Bootle (pages 372–385), under the guidance of Mr. John Christie, Manager. Afterwards by special free omnibuses to the works at the northern terminus of the Liverpool Overhead Railway, and thence along the route of the railway as far as the erection had proceeded to near the Landing Stage; under the guidance of Mr. James H. Greathead, Joint Engineer, and Mr. Ferdinand Hudleston, Contractor's Engineer.

The White Star R.M.S. "Majestic" (pages 432–433), belonging to Messrs. Ismay Imrie and Co., and ready to start the same night on her voyage to New York, was visited under the guidance of Mr. W. S. Graves and Mr. James H. Ismay.

The following Works in Liverpool were opened to the visit of the Members, as also on Wednesday and Thursday afternoons. Descriptions of most of these are given in pages 442–464.

Liverpool Gas Works, Linacre Road, Linacre; and Spofforth Road, Wavertree.
Liverpool Electric Supply Works, 13–19 Highfield Street.
Liverpool Hydraulic Power Works, 123 Athol Street.
Messrs. Cope Brothers and Co., Tobacco Factory, 10–26 Lord Nelson Street.
Dunbar's Cask Machinery, Messrs. Whyte's Cooperage Works, Watkinson Street, Queen's Dock.
Messrs. Earles and King, Liverpool Oil Mill, 65 Burlington Street.
Edmund Street Rice Mills, 51 Bixteth Street, Tithebarn Street.
Messrs. R. and J. Evans and Co., Shipbuilding Works, Brunswick Graving Dock.
Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street.
Messrs. H. and C. Grayson, Regent Engine Works, 179 Regent Road.
Messrs. John Jones and Sons, St. George's Iron Works, Cotton Street.
London and North Western Railway Goods Stations, Bankfield Street and Regent Road; and Gravitation Sidings, Edge Hill.

* The notices here given of the various Works &c. visited in connection with the meeting were kindly supplied for the information of the Members by the respective proprietors or authorities.

Mersey Forge, 89 Caryl Street.

Messrs. Francis Morton and Co., Hamilton Iron Works, Garston.

Messrs. W. H. Potter and Sons, Shipbuilding Works, Baffin Street, Queen's Dock.

Messrs. David Rollo and Sons, Fulton Engine Works and Foundry, 33–41 Sandhills Lane, Sandon Dock; and 10 Fulton Street.

Messrs. Thomas Royden and Sons, Shipbuilding Works, Baffin Street, Queen's Dock.

Messrs. John H. Wilson and Co., Bankhall Engine Works, 43–47 Sandhills Lane, Sandon Dock.

Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.

Messrs. Clover Clayton and Co., Shipbuilding Works, Woodside Graving Dock, Birkenhead.

Messrs. Cochran and Co., Engineering Works, 54 Duke Street, Birkenhead.

Messrs. Lever Brothers, Soap Manufactory, Port Sunlight, near Birkenhead.

S.S. "Columbian," Leyland Line, Atlantic Cattle Steamer.

Norton Water Tower, Norton, near Runcorn.

In the evening the Members were invited by his Worship the Mayor of Liverpool, Joseph B. Morgan, Esq., and the Mayoress, Miss Morgan, to an "At Home" in the Walker Art Gallery and the Liverpool Free Library and Museum.

On WEDNESDAY AFTERNOON, 29th July, after luncheon at the Adelphi Hotel by invitation of the Local Committee, a visit was made by special free omnibuses to the Walker Engineering Laboratories, University College (pages 386–417 and 433–436), under the guidance of Professor H. S. Hele-Shaw on behalf of the Council and Senate of University College.

In the evening the Institution Dinner was held in the Adelphi Hotel, and was largely attended by the Members and their friends. The President occupied the chair; and the following Guests accepted the invitations sent to them, though some were unavoidably prevented at the last from being present.

Reception Committee.—His Worship the Mayor of Liverpool, Joseph B. Morgan, Esq., *Chairman.* Mr. Thomas B. Royden, M.P., *Vice-Chairman.* Mr. Geo. Heaton Daglish, *Honorary Treasurer.* Mr. Henry H. West, *Honorary Secretary.* Mr. John A. F. Aspinall;

Mr. R. R. Bevis; Mr. W. S. Graves, J.P.; Mr. Ferdinand Hudleston; Alderman John Hughes, J.P.; Mr. R. E. Johnston; Mr. William Laird, J.P.; Mr. A. G. Lyster; Mr. C. A. Rowlandson; Mr. Henry Shield; Mr. Edmund Taylor, J.P.; Mr. J. H. T. Turner.

Authors of Papers.—Mr. Alfred Blechynden; Professor H. S. Hele-Shaw; Mr. Joseph Parry; Mr. E. Leader Williams.

Mr. James Abernethy, F.R.S.E., Past-President of the Institution of Civil Engineers; Sir James J. Allport, Director of the Midland Railway; Mr. G. J. Armytage, Chairman of the Lancashire and Yorkshire Railway; Mr. H. P. Boulnois, City Engineer; Mr. John Brancker, J.P., Chairman of the Mersey Docks and Harbour Board; Mr. Henry Brunner, Chairman of the Society of Chemical Industry; Mr. John Christie, Manager of the Liverpool Grain Storage and Transit Company; Mr. Peter Cowell, Librarian of the Free Library; Mr. George F. Deacon, Engineer of the Vyrnwy Water Works; Mr. Charles Dyall, Curator of the Walker Art Gallery; Professor J. A. Ewing, F.R.S.; Mr. Harry Footner, Assistant Engineer of the London and North Western Railway; Colonel Foster, D.L., J.P., High Sheriff of Lancashire; Mr. John Garnett; Mr. J. H. Greathead, Joint Engineer of the Liverpool Overhead Railway; Mr. T. Harnett Harrisson, President of the Liverpool Architectural Society; Mr. John Hartnup, Astronomer to the Mersey Docks and Harbour Board; Rev. H. H. Higgins, Chairman of the Museum Committee; Mr. Henry H. Laird; Mr. John M. Laird; Mr. W. H. Le Mesurier, Mersey Docks and Harbour Board; Mr. George F. Lyster, Engineer-in-Chief of the Mersey Docks and Harbour Board; Mr. Edward Manisty, Manchester Ship Canal; Mr. David Meldrum, Manager of the Cheshire Lines Committee; Mr. Thomas J. Moore, Curator of the Public Museum; Captain Robert E. Pinhey, R.N., Manager of the Woodside Ferry; Sir David Radcliffe, J.P., Director of the Lancashire and Yorkshire Railway; Mr. T. Mellard Reade, Ex-President of the Liverpool Architectural Society; Mr. Frank Ree, District Goods Manager of the London and North Western Railway; Mr. J. D. Rich, Postmaster of Liverpool; Mr. G. H. Robertson, Resident Director of the National Telephone Company; Mr. James Shaw, District Passenger Superintendent of the London

and North Western Railway; Mr. Thomas Shelmerdine, Jun., City Architect and Surveyor; Mr. Marshall Stevens, General Manager of the Manchester Ship Canal; Lieutenant M. A. Sweny, R.N., Marine Surveyor of the Mersey Conservancy; Mr. A. Norman Tate, Ex-Chairman of the Society of Chemical Industry; Mr. Fletcher T. Turton, Deputy Corporation Surveyor; John Vicars, Esq., Mayor of Bootle; Mr. W. Whittingham, Comptroller of the Liverpool Post Office; Mr. John C. Windle, District Goods Manager of the Lancashire and Yorkshire Railway; Mr. J. T. Wood, President Elect of the Liverpool Engineering Society.

The President was supported by the following Officers of the Institution:—*Past-Presidents*, Mr. Edward H. Carbutt, Mr. Charles Cochrane, Mr. Jeremiah Head, and Mr. Percy G. B. Westmacott; *Vice-President*, Sir James N. Douglass, F.R.S.; *Members of Council*, Mr. Benjamin A. Dobson, Mr. Samuel W. Johnson, Mr. William Laird, Mr. William H. Maw, and Mr. J. Hartley Wicksteed.

After the usual loyal toasts, the President proposed "The Mayor of Liverpool," which was acknowledged by his Worship, Joseph B. Morgan, Esq. The toast of "The Town and Trade of Liverpool," proposed by Mr. Charles Cochrane, Past-President, was acknowledged by Mr. John Brancker, J.P., Chairman of the Mersey Docks and Harbour Board. Mr. Edward H. Carbutt, Past-President, proposed the toast of "The Reception Committee," which was acknowledged by Mr. Thomas B. Royden, M.P., Vice-Chairman. The toast of "The Honorary Treasurer and the Honorary Secretary," proposed by Mr. Jeremiah Head, Past-President, was acknowledged by Mr. Geo. Heaton Daglish and Mr. Henry H. West. Mr. Henry Shield proposed the final toast of "The President," by whom it was acknowledged.

On THURSDAY, 30th July, two alternative Excursions were made

By special free train, omnibuses, steamer, and brakes, one Excursion was made to the Works of the Mersey Docks and Harbour Board (pages 436–440), under the guidance of Mr. Anthony George Lyster, Assistant Engineer; the Mersey Tunnel Railway

(pages 440–442), under the guidance of Mr. C. A. Rowlandson, Resident Engineer and Traffic Manager; Messrs. Laird Brothers' Iron Works and Boiler Works (pages 451–453), under the guidance of Messrs. Laird Brothers; and the Inman and International R.M.S. "City of Paris" (pages 454–455), just returned from an Atlantic voyage. The Members were invited by the Local Committee to luncheon on board the steamer "Claughton," during a trip up and down the Mersey in crossing from Liverpool to Birkenhead.

By special free train another Excursion was made to the Horwich Locomotive Works of the Lancashire and Yorkshire Railway (pages 456–457), under the guidance of Mr. John A. F. Aspinall, Chief Mechanical Engineer. The Members were joined at Horwich by Mr. John Ramsbottom, Past-President; and were invited to luncheon by the Directors of the Lancashire and Yorkshire Railway.

On FRIDAY, 31st July, an Excursion was made to the Manchester Ship Canal (pages 457–461), under the guidance of Mr. E. Leader Williams, Engineer in Chief, starting from Pomona Dock, Manchester, in a special train of open trucks, and proceeding along the route of the Canal to Weston Point beyond Runcorn, with an interval for luncheon at Wilderspool, near Warrington.

R.M.S. "MAJESTIC."

This vessel and her sister ship the "Teutonic" were built by Messrs. Harland and Wolff, Belfast, for the White Star Line, of which Messrs. Ismay, Imrie and Co., are the managers. These are the longest vessels afloat. Their principal dimensions are:—length over all 582 feet; breadth 57½ feet; depth 39⅓ feet; gross tonnage nearly 10,000 tons. They are built of Siemens-Martin steel, and propelled by two independent sets of triple-expansion engines driving twin-screws with manganese-bronze blades, and developing 18,000 indicated horse-power. In each set of engines the cylinders are

43 inches, 68 inches, and 110 inches diameter, with 5 feet stroke. Both engines and boilers are set below the water-line, like those of a man-of-war, for enabling the vessel to act as an armed cruiser in time of war. The two sets of engines are separated by a longitudinal bulkhead, which gives additional rigidity and strength to the vessel, and also adds to her safety; for, being fitted with twin screws, in the event of the disablement of one set of engines, the other set can carry her to her destination. The "Majestic" and "Teutonic" have only three masts, instead of four as has been usual in the White Star steamers; the masts have no yards, and carry only fore and aft steadying sails. These vessels are so constructed that at 48 hours' notice they could take their places as armed cruisers carrying twelve 36-pounder breech-loading guns; at least half their crews are naval reserve men. A vessel thus armed, and steaming twenty knots an hour, would be most valuable as a convoy, scout, or blockade runner in time of war. The "Majestic" and "Teutonic" made ten passages to and from New York during 1890, averaging about 5 days 22 hours either way.

The White Star Line, starting with the "Oceanic" in 1869, now comprises a fleet of sixteen vessels; and with the "Britannic" and "Germanic" in 1875 shortened the voyage across the Atlantic to less than eight days, as against the ten and twelve which were then the rule. The "Majestic" recently made the passage from Queenstown to Sandy Hook off New York in 5 days 18 hours 8 minutes; and she in turn has since had to give place to the "Teutonic," which has accomplished the passage in 5 days 16 hours 31 minutes.

WALKER ENGINEERING LABORATORIES, UNIVERSITY COLLEGE, LIVERPOOL.

The main building is three storied, built in terra-cotta and grey brick, of which the rest of the College buildings are being constructed. The new infirmary, as well as the chemical laboratories, are already completed; and the new library, clock tower, and other portions of the new Arts wing are in process of construction. The

vestibule of the laboratories is reached through an arch of terra-cotta work of Norman character, beyond which a few steps lead up to the main entrance of the hall, separated from it by a screen of folding doors. The hall has walls decorated with faïence work, and a floor paved with a mosaic pattern. On the right is a balcony looking over the main laboratory, and arranged so that the work going on may be seen without the necessity of entering the laboratory itself. Passing straight onwards, on the left is the students' cloak and dressing room, round which runs an iron gallery, whereon are lockers for coats and clothes suitable for workshop use.

Descending a few steps, immediately in front is the wood-working department, separated from the main building by a fire-proof floor; to the right is a side door into the main laboratory and workshop. The portion devoted to laboratory work is screened off from the workshop. In the laboratory is a 100-ton Wicksteed testing machine, fitted with alternative centres, by which it can be converted into a 20-ton machine. The details of this machine are described in Professor Hele-Shaw's paper (pages 394–397). Other smaller machines for testing the strength of materials, the properties of lubricants &c., are also placed here. The main workshop is well stocked with tools. At the end is the dynamo for generating the electric current, by which the main building can be lighted. In common with all the machinery in the place, the dynamo is driven by a vertical engine of 40 horse-power, which actuates the main shafting that runs along the centre of the laboratory; the counter-shafting for the various machines is on either side, attached to the main girders. Above is a travelling crane, running from one end of the laboratory to the other. Near the vertical engine is the experimental marine engine, of which a description is given in Professor Hele-Shaw's paper (pages 386–393). Near this engine is a large lathe, a shaping machine, a drilling machine, and a Worthington pump for hydraulic experiments.

In the adjoining boiler-house is a Robey boiler of locomotive type for supplying steam to the smaller laboratory engine; and a large marine experimental boiler for the larger engine. Also one of the experimental tanks for measuring feed-water &c.; and a small forge

and anvil; and a furnace for melting brass and iron in connection with a small foundry. Beneath the floor are the coal bunkers, and the three furnaces by which the whole building is heated on the high-pressure hot-water system of Messrs. King of Liverpool.

In the wood-working room, which is 100 feet in length, is a range of carpenters' benches, and along the wall a row of ten wood-working lathes driven by a 12 horse-power gas-engine, which also actuates a general joiner, consisting of a circular saw and wood-planing and moulding machine. There are also other wood-working tools, such as a band-saw and hand-planer, and an emery grinding machine; also a dynamo by which the carpenters' shop is lighted.

The museum on the first floor is reached either by the stone staircase from the main hall, or by a spiral iron staircase from the main laboratory. It contains already some cases, although at present it has but few models or specimens. It is hoped it will become of great importance as an educational feature, for showing not only engineering models, but also specimens illustrating corrosion and fracture, and wear resulting from friction, and also examples of the various materials used in engineering construction. Such museums, although occupying an important place in similar institutions abroad, have not at present been made a sufficiently prominent feature of engineering colleges in this country.

The lecture hall, reached from the museum, has been well fitted as regards arrangements of the black-board and lecture table and lantern. It is found to have excellent acoustic properties, and there are separate desks for 128 students.

In the apparatus room, adjoining the lecture hall, models for lectures are made. Next to it is a large class room. Beyond is the professor's private room, with ante-room forming the assistant's room. The passage from the museum leads by a staircase up to a mezzanine floor, from which the upper tier of seats in the lecture hall is reached; this floor overlooks the museum from a balcony. At the end of the top corridor is the drawing hall, occupying the whole width of the building, and well lighted on the north, east, and west; the artificial lights consist of gas pendants,

not combined with electric light as elsewhere. Separate electric lights hang from the roof over each of the fifty drawing tables, of which each student has one. Adjoining the drawing hall is the lecturer's room, and the private room of the assistant lecturer on engineering; also a smaller class room and the students' common room. Above the latter, in a portion of the roof, is constructed a photographic and dark room; also a room lighted by a skylight, where copies of engineering drawings and tracings may be made.

MERSEY DOCK ESTATE.

North Dock Works.—The system of docks comprising the Hornby, Alexandra, and Langton Docks, Plate 99, connected with the river by the Canada Basin, is that most recently constructed for the accommodation of the largest class of vessels, and is now used by the great transatlantic liners. The area of the Alexandra Dock, the largest of the group, is about 44 acres, and its quayage 4,000 lineal yards. The quays are provided with sheds for the shelter of cargo; these are for the most part 95 feet wide, in one span. On the north quay of the Langton Dock is a double-storey shed, with roof cranes of the kind employed at the Toxteth Dock.

The Canada Basin and the approaches thereto are kept clear of silt by an elaborate system of sluices in the side walls and floor of the basin, and in the base of the north and south jetties at its entrance. Through these, large volumes of water are allowed to flow at low water, to sluice away the silt deposited from the highly charged water of the estuary, which tends to accumulate rapidly in all open basins. The largest of the main sluicing culverts is 13 feet wide by 15 feet high; the outlets in the side walls are 4×4 feet and 6×6 feet. The underfloor pipes are 8 feet diameter, and the upshoots from them 3 feet diameter, each having a cover to assist in distributing the water around it. The sills are laid at a depth of 12 feet below "Old Dock Sill" datum, giving a depth of water of 31 feet on the sill at high water of ordinary spring tides. The gates to all the entrances and passages are of greenheart timber.

The dock gates, bridges, capstans, sluice machines, &c., are worked by hydraulic power, the pressure water being supplied from the centre at the Langton Graving Docks, Plate 99.

Langton Graving Docks.—These docks are two in number, each 950 feet long, and having a pair of inner gates by which it can be divided into lengths of 450 and 500 feet. The chambers of these docks are built entirely of concrete; only the quoins &c. at the entrances are of dressed stone. In many cases the water can be run off from these docks at low water; but pumps have to be provided to empty them on unfavourable tides, and also to clear them of leakage on all tides. The wells, two in number, are situated in the engine house between the entrances. Each well has a turbine pump for dealing with the bulk of the water which cannot be run off, and a set of chain pumps to take the leakage. These are driven by two horizontal Corliss-valve jet-condensing steam-engines, made by Messrs. Hick, Hargreaves and Co., of Bolton, who also supplied the turbine pumps.

Hydraulic Power Centre.—In the same block of buildings are situated the main hydraulic pumping engines supplying pressure water to this district of the Dock Estate at a pressure of 700 lbs. per square inch. These engines are horizontal condensing engines of 350 indicated horse-power, made by Sir W. G. Armstrong and Co., who also supplied most of the hydraulic machinery for this section of the docks. The accumulator at the east end of the building is 24 inches diameter and 40 feet stroke.

100-*Ton Crane.*—This crane, situated on the south side of Langton Branch Dock, lifts the weight by the direct action of an inverted hydraulic cylinder, in which the stroke of the piston is 50 feet.

30-*Ton Crane.*—Situated between the graving docks, this crane has the special feature that it is capable of being moved along the quay, and of taking up a position to serve any one of the four graving dock chambers. Both these cranes were made by Sir W. G. Armstrong, Mitchell and Co.

Canada and Huskisson Docks Improvement Works.—Works are now in hand with the object of making the Canada and Huskisson

Docks available for vessels of the largest class. The scheme includes the deepening and lengthening of the Canada 100 feet lock, the improvement of the west quay of Canada Dock, the construction of a new branch dock, and the construction of a new deep-water half-tide dock on the site of Sandon Basin and Wellington half-tide dock, which will serve as a vestibule to the altered Canada-Huskisson system, and to the docks lying to the southward, in all of which water for vessels of the deepest draft will be maintained at all times. A new deep-water graving dock will also be constructed. The excavation of the branch dock and formation of its walls in concrete are now in hand, and the north side of No. 2 Huskisson Branch Dock is being extended 230 feet as part of the new dam between the Huskisson and Canada Docks, through which a passage 80 feet wide will be formed. The existing dam and passages in line of Battery Street will be entirely removed. Work is now also being carried forward at the west wall of Canada Dock, the Canada 100 feet lock, and the approaches thereto in the Canada Basin, Plate 99.

Coburg Pumping Station.—This installation of pumps has been provided to maintain water in the old docks, Plate 100, from Brunswick to George's inclusive, 80 acres in area, at such a level as will allow of their use by vessels of deep draft. Without this aid they would not be available on neap tides for any but light-draft vessels, as the sills and bottoms of the docks are at a comparatively high level, and as in the approaches to their entrances the Pluckington Bank rises to about the level of the present sills, which forbids their being lowered. The Brunswick-George's group is therefore now worked as an impounded system, approached by deep-draft vessels by way of the Union Dock which serves as a lock, and of the chain of new docks southward thereof, whose sills are laid at the low level of 12 feet below Old Dock sill. Light-draft vessels however can enter as heretofore by way of the outer docks, Brunswick half-tide dock, Coburg Dock, Queen's and Canning half-tide docks, and can be locked up to the level of the inner docks. There are at this station three centrifugal pumps of the "Invincible" type, made by Messrs. J. and H. Gwynne. Their principal dimensions are as follows:—fans 90 inches diameter, suction and delivery pipes 54 inches

diameter, pump casing 16½ feet diameter. They are driven by vertical inverted compound surface-condensing direct-acting engines arranged tandem fashion, independent of each other and having the following dimensions:—high-pressure cylinder 22 inches diameter, low-pressure 40 inches diameter, stroke 30 inches, revolutions 90 per minute. Steam is supplied at 100 lbs. pressure per square inch from five steel Lancashire boilers, 30 feet long and 7 feet 6 inches diameter. The pumps have delivered about 1,200 tons per minute, or 400 tons per minute each pump, and are fully capable of doing the work required of them.

Double-Storey Shed, Toxteth Dock.—The double-storey sheds have been designed to allow of the rapid discharge of cargo from vessels, for which purpose large area of shed floor is required for the sorting &c. of cargo. The chief dimensions of this shed are, length 1,360 feet, width 95 feet outside; it is divided by brick walls into five compartments. The ground floor is partly paved with granite sets, and partly asphalte on macadam. The upper floor is on wrought-iron main girders and floor beams, covered with buckled plates on which are laid tiles set in cement. This floor is supported by brick side-walls and piers. The roof is of light wrought-iron, supported on wrought-iron columns. For the discharge of goods from the ships to the upper floor, special hydraulic cranes have been designed by Mr. Lyster. They can each lift 30 cwts. with a radius of 35 feet, and are arranged to travel on rails laid along the ridge and eave of the shed, so as to be brought into position to suit any hatch of a ship. In order to allow of goods being discharged at any point, the dock side of the roof is carried on iron columns, and continuous iron doors are provided. Hand jiggers are placed on the road side of the upper storey, and over hatchways, for lowering goods from the upper floor down into carts.

Petroleum Stores at Herculaneum Dock.—There are sixty magazines capable of holding in all about 60,000 barrels. They are excavated in the cliffs on the east and south quays of the Herculaneum Dock, Plate 100, and are separated from each other by walls of solid rock, and are provided with wrought-iron doors. The sills of the doorways are raised to a height of 4½ feet above the floor, so as to render each

magazine capable of containing the whole contents of the barrels in bulk, in case any accident should occur.

On the land to the south of Herculaneum Dock four petroleum tanks have recently been provided, two of 2,000 tons each, one of 2,500, and one of 3,000 tons. Each tank is surrounded by a concrete embankment, forming a moat capable of containing the whole contents of the tank. For the reception of the oil, the tank ship bringing oil for any of these tanks is berthed on the west side of the Herculaneum Branch Dock, and by her pumps discharges her liquid cargo through pipes laid underground into the land tanks, the bottom of which is some 15 feet above the level of the dock quay. For delivery of oil, pipes are laid from the tanks into filling houses on a terrace lower down the slope of the land. Here the barrels are filled by gravitation, and loaded upon carts or wagons direct from the floor of the filling house; or bulk wagons standing on the rails may be filled direct by a pipe from the filling house. Empty barrels that are to be filled are brought to the dock quay, and then lifted by a barrel elevator worked by a gas engine. From the top of the elevator a runway laid at a suitable slope leads to the several barrel yards, into which the barrels are delivered for cleaning, coopering, glueing, and painting, before filling.

MERSEY TUNNEL RAILWAY.

This railway connects Liverpool with Birkenhead by a tunnel under the Mersey, which is here 1,320 yards or three-quarters of a mile wide, Plate 101.* It begins at the Central Station of the Cheshire Lines in Liverpool, and is constructed almost entirely in tunnel, lined throughout with brick in cement, and laid with a double line of steel rails, of bull-head section, weighing 86 lbs. per yard, on sleepers spaced 2 ft. 3½ ins. centre to centre. Under the river the tunnel is in sandstone rock, with a cover of 30 to 35 feet

* See papers by Mr. Francis Fox and Mr. W. E. Rich in the Proceedings of the Institution of Civil Engineers, vol. lxxxvi, 1886, pages 40–79, from which this description has been mainly derived and Plate 101 prepared.

between the river bed and the top of the tunnel. The lowest level is 145 feet below mean high-water mark, and the gradient on the Liverpool side is 1 in 27 for a short distance.

The tunnel is drained by a heading beneath of 7 ft. 4 ins. diameter, through which the water runs into two pumping shafts, one on each side of the river, where it is raised 170 feet. On the Liverpool side there are three pumping engines: one a compound overhanging-beam engine of 200 horse-power, with double-acting cylinders of 36 and 55 inches diameter and 10½ feet and 13 feet stroke respectively, working a plunger pump of 40 inches diameter and 15 feet stroke; and two compound horizontal engines, working two pairs of double lifting or bucket pumps of 20 and 30 inches diameter and 6 and 10 feet stroke respectively, in balanced sets from quadrants. One of the horizontal engines has cylinders of 20 and 35 inches diameter and 6 feet stroke; in the other the cylinders are 33 and 60 inches diameter with 10 feet stroke; both are fitted with differential valve-gear. On the Birkenhead side there are two vertical pumping engines, each working a plunger pump of 40 inches diameter and 15 feet stroke; and one horizontal engine working lifting pumps of 30 inches diameter and 8 feet stroke.

For the ventilation of the tunnel four Guibal fans are kept constantly at work; two are 40 feet diameter and 12 feet wide, and two are 30 feet diameter and 10 feet wide; one of each size is erected at Liverpool and one at Birkenhead. The larger are each driven by a tandem compound condensing engine of 120 horse-power, having cylinders of 20 and 33 inches diameter and 2½ feet stroke; and there is a stand-by non-condensing engine with single cylinder of 33 inches diameter and 2½ feet stroke. The smaller fans are each driven by a similar engine with cylinders of 15 and 24 inches diameter and 2 feet stroke; and the stand-by engine has a single cylinder of 34 inches diameter and 2 feet stroke. The four fans, running at about 45 revolutions per minute, together exhaust about 580,000 cubic feet of air per minute, equal to about one-seventh of the total capacity of the tunnel. They exhaust from a separate heading or drift of 7 ft. 4 ins. diameter, running alongside the tunnel; and frequent openings from the tunnel into the fan drift,

which are fitted with sliding doors, afford the means of distributing the exhausting action as desired. Fresh air is admitted into the tunnel at the stations.

On each side of the river three hydraulic lifts are provided for raising passengers from the underground stations to the street level; the height of lift is 76½ feet in Liverpool, and 87½ feet in Birkenhead. Each lift accommodates one hundred passengers; the average speed is 120 feet per minute. The rams are composed of steel tubes 18 inches outside diameter, screwed together in lengths of 11½ feet. The average pressure is 70 to 75 lbs. per square inch, obtained from water tanks at the top of lofty towers. The tanks are kept full by small pumping engines, and the same water is used over and over again continuously. The lifts are balanced to the extent of about two-thirds of the weight of their cages and rams. The cages are lighted by ordinary gas, supplied through flexible tubes.

The locomotives in working order weigh nearly 68 tons, having inside cylinders 21 inches diameter by 26 inches stroke, and six coupled wheels of 4 ft. 6 ins. diameter, and a four-wheeled bogie, making ten wheels in all. The carriages are lighted with compressed oil-gas, and fitted with continuous automatic vacuum brakes. About 300 trains pass through the tunnel daily, the maximum service being a train each way every five minutes.

The preliminary works were begun in December 1879, the main works in August 1881, and the traffic commenced in February 1886. The engineers are Sir James Brunlees and Sir Douglas Fox, assisted by Mr. Francis Fox.

LIVERPOOL ELECTRIC SUPPLY WORKS.

The Liverpool Electric Supply Co., supplying electric light throughout a large portion of Liverpool, has three central stations, of which the most complete is situated, with the offices and works, in Highfield Street, close to the Exchange Station of the Lancashire and Yorkshire Railway. The mode of supply is by low-tension direct

current at a pressure of 110 volts. Each set of machinery consists of a dynamo driven by a Willans compound engine fixed on the same bedplate, and is capable of maintaining 1,500 incandescent lamps of sixteen candle-power. The dynamos are all arranged to run in simple parallel. Steam is supplied to the engines by double-flued or Lancashire boilers 28 feet long and $7\frac{1}{2}$ feet diameter. During the hours of least demand the engines are stopped, and the current is supplied from accumulators. The cells used are made by the Electric Construction Co., and the Crompton-Howell Electrical Storage Co., and are contained in boxes 4 feet long, 12 inches wide, and 13 inches deep. The distributing mains are laid underground in iron troughs filled in with bitumen, on the Callender plan. More than twenty miles of mains have already been laid; and current is now being supplied for 13,000 incandescent lamps of sixteen candle-power.

LIVERPOOL HYDRAULIC POWER WORKS.

Between fifteen and sixteen miles of hydraulic mains are at present laid in Liverpool, extending from Toxteth Dock at the south to Bootle at the north, and as far back from the river as St. Anne Street; and extensions are being made as required. The mains in the streets vary from 6 inches internal diameter in the principal lines to 2 inches for service pipes into consumers' premises. They are of cast-iron of standard sizes with strong flanges, the joints being bored and turned and made with a gutta-percha ring. The mains are laid in circuit, as far as possible; and there are controlling valves at about every 400 yards, so that any section can be isolated for repairs or extensions. The pumping station is situated in Athol Street, on the west bank of the Leeds and Liverpool Canal. The water for the mains was at first drawn from the canal, and passed through tanks and filters provided over the engine and boiler houses; but an arrangement has since been come to with the Liverpool corporation, and water from their mains is now used which obviates the necessity of filtration.

The mains are kept charged by powerful pumping engines; there are already at work two sets of Ellington's triple compound condensing engines of 200 indicated horse-power each, made by the Hydraulic Engineering Co., of Chester. A third set is now in course of construction, and provision is made in the engine-room foundations for more as they may be required. Steam is supplied by three Lancashire boilers, 30 feet long, and 7½ feet diameter, fitted with Vicars mechanical stokers, which are driven, along with a Green economiser, by a Brotherhood three-cylinder hydraulic engine. The pressure is maintained in the mains by two accumulators, with rams 18 inches diameter and 20 feet stroke, loaded to a pressure of 750 lbs. per square inch.

These works have now been in operation for three years, and are supplying a large amount of hydraulic power for various purposes with the most economical and satisfactory results, and the number of consumers is constantly increasing. About two hundred machines are at present being worked from the high-pressure mains, including lifts and jigger hoists in warehouses for the expeditious storage and delivery of goods, passenger lifts in hotels and office buildings, presses, motors, &c. The cost of lifting by this power is in some cases as low as one farthing per ton lifted fifty feet high. The pressure water is charged for on a sliding scale, and is registered by meters fixed on the exhaust pipes of the machines, from which the water is allowed to run to waste. The power is available day and night, and on Sundays if required.

MACHINE COOPERAGE.

This cooperage, belonging to Messrs. John G. Whyte and Co., and situated in Watkinson Street, Queen's Dock, is employed exclusively in the manufacture of palm-oil casks by machinery supplied by Dunbar's Cask Machinery Co., Liverpool. The staves are taken in the rough, and passed successively through a dresser, side and end cutters, and a jointer. The cask is then raised, heated, trussed, and worked off ready for heads, which are also made

throughout by machinery. The special feature of the works is that the whole process is conducted without the assistance of coopers.

LIVERPOOL OIL MILL.

This mill, belonging to Messrs. Earles and King, was established in Oil Street in 1804. The ground then occupied being required for the extension of the London and North Western Railway goods station, the present mill was built in 1872 at 65 Burlington Street, with all modern improvements. The principal industry is the crushing of linseed, the extraction of oil therefrom, and the manufacture of linseed cakes. Seven hundred tons of linseed can here be crushed each week, producing about 460 tons of cake and 240 tons of oil. As the oil is used chiefly for painting, about one third of the quantity made is boiled, so as to promote its drying qualities. For this purpose there are two boiling pans, each capable of holding eight tons of oil; and as about ten hours are required to complete the process of boiling, fresh lots of oil can be boiled day and night. For the pressing of the seed into cake there are twenty-eight hydraulic presses, the larger of which can exert a pressure of 400 tons. The seed is first crushed between chilled-iron rollers, and then heated, or cooked in steam kettles, after which it is placed between woollen wrappers and taken to the hydraulic presses. Here the greater part of the oil is extracted, and the residue is the cake. On coming out of the presses the edges of the cake are soft and oily, and are pared off by mechanical paring tables in order to render the cakes firm and marketable. They are then cooled in racks, after which they are ready for the market. A compound feeding cake, used largely, and with great advantage, for milch cows, is also made here from different suitable ingredients. The firm have their own cooperage, joiners' and pattern shop; fitting shop, where they make their own machinery; and saddlers' shop, where their own belting is made, and harness for the horses. The underground fireproof vaults are capable of holding upwards of 40,000 bags of linseed. The mill itself is also fireproof, being arched above and below.

EDMUND STREET RICE MILLS.

These are the oldest rice mills in England, having being erected over a hundred years ago for the manufacture of Carolina rice. After the American war the Carolina supply ceased, and was replaced by Burma and India rice, with increased trade. These mills can treat about 800 tons of rice and grind 180 tons of rice flour per week. The flour machinery, which requires about 120 horse-power to drive it, is driven through a friction clutch so that it can be thrown in or out of gear while the engine is running. The engine is horizontal tandem compound, indicating 450 horse-power, and drives the mill from a fly-wheel 20 feet diameter by means of sixteen cotton ropes. Steam is supplied at a pressure of 100 lbs. per square inch from three boilers, all fitted with Bennis mechanical stokers, which effect great economy in fuel and are successful in preventing smoke. Mr. Frederick Dresser's cement for artificial mill-stones can be seen in preparation and at work. During recent years large rice-cleaning mills have been erected in Burma and India, and the cleaning of rice in England is rapidly becoming extinct, as it can now be done cheaper abroad. These mills will soon be closed and reconstructed for other business.

SHIPBUILDING WORKS, BRUNSWICK GRAVING DOCK.

These works, belonging to Messrs. R. and J. Evans and Co., are situated at Brunswick Graving Dock; and the machinery and appliances here employed are such as are generally used in iron-shipbuilding yards.

PHŒNIX FOUNDRY.

These engineering works, the property of Messrs. Fawcett, Preston and Co., are the oldest in Liverpool, having been established in 1775. At first they occupied merely a small space at the corner of York Street and Lydia Ann Street: but they have been gradually extended

from time to time until they now occupy the entire area enclosed by four streets. To increase their capacity for turning out work and to economise labour, extensive alterations have lately been made in the buildings and machinery of the works at York Street, especially in the erecting shops and iron foundry.

Mr. Fawcett, who was among the first to apply steam to the propulsion of vessels, built the engines of the "Etna," which began to ply on the Mersey in 1817; and in 1840 the firm made the machinery of the "President," the largest Atlantic steamer built up to that time. Between 1817 and 1840 they supplied to the home and foreign governments, and to the leading steamship companies, over 170 sets of marine engines of varying powers, up to 540 horse-power nominal, which was the power of the "President." Hall's surface condenser, the first ever applied to marine engines, was here fitted to the "Windermere" in 1835.

Since the beginning of this century the firm have also been makers of all kinds of machinery for the manufacture of sugar from the cane, and have recently introduced many improvements in the design of cane-crushing mills, multiple-effect vacuum apparatus for evaporating the water from the cane juice, and stills for making rum from the molasses; examples of each can be seen in various stages of manufacture. Their system of multiple-effect evaporation has been applied successfully to the economical distillation of fresh water from sea-water; and in 1886 two plants were made by them and erected at Suakim to the order of the government, for the supply of drinking water to the English troops, each plant being capable of producing about 48,000 gallons per day. The same system has been largely applied to the evaporation of water from alkaline and other solutions; and several sets of apparatus for the recovery of soda ash from the spent liquors used in paper works in England and Ireland are in course of construction. For some years past these works have also been noted for the construction of machinery for the manufacture of nitrate of soda; and several of the best appointed nitrate works in Chili are fitted with machinery which was designed and manufactured here. The Cyclone press of Mr. James Watson is also manufactured here; and three of the largest presses ever made,

weighing about 95 tons each, have been constructed and shipped this year to India and China, with their complete sets of pumps and engines, for pressing jute, cotton, silk, feathers, &c. One of these presses, now at work in India, of which a working model can be seen in action, has made over sixty bales an hour. A plantation press on a new plan is also in course of construction. The manufacture of steam-boilers, and copper work, forming an important branch of the business, is carried on at the Lightbody Street works, which are of modern construction, and are fitted with powerful tools and special appliances.

ST. GEORGE'S IRON WORKS.

These works were established in 1850 for the manufacture of locomotives, and stationary and marine work; lately there have been added a shipbuilding yard and forge. They belong to Messrs. John Jones and Sons, who are the only firm in Liverpool conducting in their own premises shipbuilding, engineering, forge, and foundry work. In 1853 they fitted out some of the first stern-wheel steamers built in this country, shipped them in parts to India, and there put them together on the rivers, as well as light-draught paddle steamers. In 1857 the "Iron Duke," a large paddle steamer of the City of Dublin Steam Packet Co., was cut in two and lengthened 40 feet, being the first iron steamer lengthened in this country; she was afterwards fitted with new boilers, and still continues to perform her work in the most satisfactory manner. In 1878 the extremely full modelled ships for cargo purposes were here introduced, of which the "Benan" was the pioneer; this has now become the accepted type for cargo steamers. During the last few years steamers of every description have been built and engined by this firm; and a large set of tri-compound engines are now being completed for a screw steamer of 7,000 tons burden, the boilers of which weigh 70 tons each and are constructed for a working pressure of 180 lbs. per square inch. Rotary engines have also been applied satisfactorily, in cases where the consumption of steam was not of primary importance.

MERSEY FORGE.

These works were established in 1824 for the manufacture of forgings of the largest size then required. For many years the hammers were of the belly-helve description; but these have now been all superseded by steam hammers. These works were amongst the first to lay down plant for the manufacture of Bessemer steel and armour plates; but these branches not proving remunerative were afterwards abandoned and the machinery dismantled. At present they are engaged exclusively on the manufacture and finishing of forgings in iron and Siemens steel, especially crankshafts, line shafts, and stern and rudder frames for steamers up to the largest class. Here were constructed the stern frames of the "City of Rome," "La Champagne," and "La Bourgogne," and the crankshafts of the "Servia" and "Normandie."

The forge comprises one 12-ton, four 7-ton, one 5-ton, and several smaller steam hammers; and the machine shop is supplied with lathes, slotting and planing machines, of the largest and most powerful description. Here is made a special brand of iron prepared from cold-blast and all-mine pig-irons, for the construction of forgings of the largest size, where reliability and moderate cost are desired. This material recommends itself for crank and propeller shafts of ocean steamers, and for all forgings for land engines, owing to its great power to resist torsional strains; specimens 2 feet long and 2 square inches area rarely fracture until twisted between five and six complete turns, the fracture being always fibrous.

HAMILTON IRON WORKS.

These works, belonging to Messrs. Francis Morton and Co., are situated on the Mersey at Garston near Liverpool, and cover more than ten acres, comprising a large range of lofty and well lighted buildings for the manufacture of all kinds of constructional ironwork, with private dock and railway siding accommodation. For over forty years the firm has been engaged in the manufacture of iron

roofing and fencing, of iron and steel telegraph poles, of which large quantities have been supplied to the Indian and other governments, and of iron and steel girders. The whole of the wrought-iron main girders, 6¼ miles in length and about 5,000 tons in weight, for the Liverpool Overhead Railway now in course of erection, are being made here, and some 1,600 tons of castings; also the steel swing-bridge for carrying this railway across the entrance to the Stanley Dock has recently been completed and delivered.

SHIPBUILDING WORKS, QUEEN'S DOCK.

These works, belonging to Messrs. W. H. Potter and Sons, are situated in Baffin Street, Queen's Dock, and were established some thirty-five years ago. Considering the small space they occupy, the large amount of work that has been turned out since they were started is remarkable.

FULTON ENGINE WORKS.

These works, belonging to Messrs. David Rollo and Sons, are employed in the construction of marine engines and boilers, and in the repairing of engines, boilers, and ships. The machine, fitting, finishing, and erecting shops are situated in Blackstone and Fulton Streets; and the boiler and pattern shops, coppersmiths' and whitesmiths' shops, iron and brass foundry, forge and smithy, are at Sandhills, and are lighted by electricity. Among the special appliances are one 140-ton hydraulic riveting machine and another of 40 tons; a machine with five drilling heads for drilling boiler shells and ends in place; a machine for flanging furnace fronts, and another for drilling them; a flanging hammer, and three drop-hammers for hot stamped work.

BANKHALL ENGINE WORKS.

These works, the property of Messrs. John H. Wilson and Co., are situated near Sandon Dock, and adjacent to the Sandhills Station of the Lancashire and Yorkshire Railway. They are employed in the manufacture of steam winches and cranes, steam-crane excavators, and concrete-mixing machines, which have been extensively used in the construction of the Manchester Ship Canal. A ten-ton steam-crane, fitted with a digging bucket having a capacity of 1½ cubic yard, will excavate and deliver into wagons from 800 to 1,000 cubic yards per day of ten hours, according to the nature of the ground; it will work a clear 22-foot face, and drive a gullet 50 feet wide. It has no limit in revolving, and therefore does not require any trimming of the bottom sides of the cutting in order to get wagon roadways in. The concrete-mixing machines, designed by Messrs. Carey and Latham, are made in various sizes capable of turning out from 10 to 70 cubic yards of concrete per hour. They both measure and mix the materials mechanically, and do their work effectively and rapidly.

BIRKENHEAD IRON WORKS.

These works belong to Messrs. Laird Brothers, whose firm was founded in 1824 by William Laird, the father of the late John Laird, M.P.; and since that date there have been built here, including work now in hand, 589 vessels, having an aggregate tonnage of over 380,000 tons, and an aggregate of over 352,000 indicated horse-power. A large portion of this work has been done for the British and foreign and colonial governments. Many famous and successful vessels of the mercantile marine have likewise been constructed here. Special attention has been given to the design and construction of steamers for river navigation, some of which have been pioneers in opening up rivers that now form important channels of commerce; among these steamers is included the "John Randolph," the first iron steamer ever seen on American waters. Among the notable ships recently turned out are the twin-

screw Atlantic liner "Columbia," built for the Hamburg American Steam Packet Co., one of the fastest and most successful ships in the Atlantic trade; and the Chilian torpedo gun-boats, "Almirante Lynch" and "Almirante Condell," which have recently distinguished themselves in several naval engagements on the coast, notably that which resulted in the sinking of the ironclad "Blanco Encalada."

Entering the works from the office, Plate 102, the model room A is on the right; B is the large engine shop, with a variety of work; and at C are shipbuilding tools, and a frame-bending furnace.

The two southernmost slips D and E are prepared for laying down H.M. ships "Onyx" and "Renard," twin-screw torpedo gun-boats, length 230 feet by 27 feet beam and $14\frac{1}{3}$ feet depth; 735 tons displacement, and 3,500 I.H.P.

At F in No. 5 graving dock lies H.M. first-class twin-screw battle ship "Royal Oak," length 375 feet by 75 feet beam and 44 feet depth; displacement 14,300 tons; power 13,000 I.H.P. Between Nos. 4 and 5 docks is a new shop fitted up with shipbuilding machinery specially adapted for the heavy work on this vessel.

At G in No. 4 graving and fitting dock lies, nearly ready for sea, the "Ibex," a steel twin-screw fast channel steamer for the Great Western Railway, 265 by $32\frac{1}{2}$ by $15\frac{1}{2}$ feet, 4,000 I.H.P., speed $19\frac{1}{2}$ knots.

In the engine erecting shop H are in course of erection the engines for the "Royal Oak," of 13,000 I.H.P.; also twin-screw engines of 4,000 I.H.P. for s.s. 582, and screw engines of 3,000 I.H.P. for s.s. 583.

On No. 2 slip I is No. 584, a steel twin-screw passenger steamer for the Brazilian coasting trade; 220 × 30 × 12 feet, 900 tons, 650 I.H.P.

On No. 1 slip K is No. 582, a twin-screw mail and passenger steamer for the Fleetwood and Belfast service of the Lancashire & Yorkshire and London & North Western Railways; $311\frac{1}{2} \times 36 \times 15\frac{3}{4}$ feet, 2,000 tons, 4,000 I.H.P. At L is shipbuilding machinery.

At M is No. 3 dock under a permanent roof, in which is building a screw steamer, No. 583, for the Atlantic cattle trade, 403 × $45\frac{1}{2}$ × $36\frac{1}{2}$ feet, 5,000 tons, 3,000 I.H.P. At N is the smithy.

At the north end of the works are the steam saw-mills O, and the joiners' shops P with mould loft, &c.

The boiler shop is situated in Beaufort Road, and opposite is Gilbrook yard, where are the "9 de Julio" and "Independencia," river ironclads for the Argentine government, 240 by 44 by 22 feet, carrying two 24-centimetre guns in barbettes, four 4·7 centimetre guns, and four 3-pounder quick-firing guns. The boiler factory was completed in September 1888, and has already turned out a large number of boilers, many of which are of exceptional size, some of the largest having weighed about 75 tons each. The ground covered by buildings is nearly 6,000 square yards. The factory consists of four principal spans, parallel to one another, the largest of which is reserved for the erecting work; it is 236 feet long by 53 feet wide and 58 feet high. The annexe on the east is the shop for receiving and preparing the material ready for erecting. Another annexe on the west is devoted to the lighter work, and still farther to the west is the smiths' shop. The factory is supplied with the most modern machinery, and with travelling cranes driven by power; it is adapted for the highest and largest class of high-pressure marine boilers. The offices for managers and foremen are near the entrance, and over these are a large drawing office and a mould loft.

BIRKENHEAD FORGE.

These works, belonging to Messrs. Clay, Inman and Co., were erected twenty-two years ago for the manufacture of wrought-iron and steel forgings of the largest description, including stern-frames and rudders. They are situated close to the graving dock and other docks in Birkenhead, with railway communication into the premises. The furnaces are worked throughout on the Siemens regenerative gas system, and the cranes by hydraulic power. There is also a turning shop, containing powerful lathes and other machinery.

R.M.S. "CITY OF PARIS."

This vessel and her sister ship the "City of New York" are the largest passenger steamers in the world. They were built by Messrs. James and George Thomson, Clydebank, for the Inman and International Steamship Co., and their principal dimensions are:—length on water line 525 feet; length over all 560 feet; breadth 63¼ feet; depth moulded 42 feet; gross tonnage 10,508 tons. They are built of Siemens-Martin steel from the works of the Steel Company of Scotland and the Mossend Steel Co.

The hulls are divided by transverse bulkheads into fifteen water-tight compartments, including three for boilers and two for machinery, the latter being further divided in each case by longitudinal bulkheads, rendering the vessels practically unsinkable. None of the compartments exceed 35 feet in length, and the quantity of water they would hold would be 1,250 tons to load water-line, or 2,250 tons to upper deck. Even were two or three compartments filled, the flotation of the vessels would not be placed in danger, and their buoyancy could easily be trimmed. The vessels have double bottoms, the inner one being over four feet above the outer; and have special rudders, formed so as to be a continuation of the lines of the vessels below the water line. The rudder was designed primarily for use in warships; and these vessels have been specially retained by the Government as armed cruisers in the event of war. They are driven by twin screws worked by separate sets of machinery, and are the first high-speed Atlantic liners so propelled. The engines are placed in two compartments separated by a longitudinal water-tight bulkhead; while transverse bulkheads on each side isolate them from other parts of the vessel. There are two sets of triple-expansion engines, each with cylinders of 45 inches, 71 inches, and 113 inches diameter, with 5 feet stroke, their total indicated horse-power being 18,000. There are nine double-ended steel boilers with six furnaces in each; the working pressure is 150 lbs. per square inch, and the total heating surface is 50,040 square feet.

The passenger accommodation includes handsome dining saloons, drawing rooms, well furnished libraries, smoking rooms for first and

second-class passengers, and barber's shops. The vessels are fitted throughout with electric light, and possess every modern improvement that has been devised for the safety and comfort of passengers. The accommodation for steerage passengers is also of the best description. The "City of Paris" made the passage westward in 5 days 19 hours 18 minutes in August 1889; and eastward in 5 days 22 hours 50 minutes in December 1889; which are among the fastest passages ever made.

SUNLIGHT SOAP WORKS.

These works, belonging to Messrs. Lever Brothers, occupy an area of 52 acres on the Bromborough Pool, opening into the Mersey above Birkenhead, and are in direct communication with the Chester and Birkenhead Railway. The main buildings cover an area of nearly four acres, and comprise the following: soapery, frame room, drying room, stamping room, offices, dining rooms, engine house, boiler shed, mechanics' and joiners' shops, electric-light room, box-making rooms, railway shed and loading stage. The soapery is a fire-proof building three storeys high, and is capable of turning out 750 tons of soap per week. At one angle of this building a tower 20 feet square and 90 feet high supports a water tank for supplying water to the sprinklers for extinguishing a fire. The boiling rooms are situated on the top floor of the soapery, where there are placed twenty-seven boiling pans, each with a capacity of 60 tons of liquid soap. The fat and other raw materials are brought to the works in casks, in which they are melted by a steam jet, and are afterwards pumped up into the boiling pans. When this boiling has completed the saponification or proper blending of the alkalis and acids, so as to avoid the presence of free or un-neutralised alkalis in the soap, which usually occupies at least ten days, the soap is allowed to stand for a time, in order that any slight sediment may settle; and then the layer of clear soap remaining above is run off through wooden spouts into frames, where it is allowed to cool, and is then removed for cutting into

slabs and bars. The pieces of soap are next taken to the stamping machines, of which there are fifty, some worked by steam and some by hand; here they are stamped into lettered tablets, after which they are wrapped up and packed into card boxes and wooden cases for transit.

In the box-making department are sawing, printing, nailing, and other machines for the manufacture of boxes and cases. The wood for the cases is first sawn up, then printed, and lastly passed through the nailing machines which fasten the parts of the case together. There are sixteen of these nailing machines, capable of turning out together over 8,000 cases per day. From 350 to 400 girls are employed in the manufacture of card boxes, and in packing the soap. The total number of persons employed in these works is over a thousand. All the ingredients used in the manufacture of the soap are analysed in the laboratory beforehand; samples are also taken during the process of manufacture and analysed; and finally, portions are taken from each batch of finished soap and subjected to a third examination, to ensure no deleterious substances remaining in the soap.

LANCASHIRE AND YORKSHIRE RAILWAY LOCOMOTIVE WORKS, HORWICH.

These works, of which the building was commenced in 1886, have been erected for the purpose of repairing and renewing the locomotive stock, and of carrying out the mechanical engineering work of the railway. They are situated between the Chorley New Road, Horwich, and Red Moss; and are about one mile distant in an easterly direction from Blackrod Station upon the main line between Manchester and Fleetwood. The land enclosed for the works comprises 85 acres, and lies north-west and south-east, Plate 103. The covered area of workshops is 15 acres. They comprise offices, general stores with gallery, boiler shops, smithy, forge, foundries, tin and copper shops, machine shops, erecting and repairing shops, &c. For the carriage of materials from the stores, and of work, to the several shops, five miles

of tramways of 18-inch gauge have been laid throughout the works, the haulage being performed by small locomotives. The cylinders are 5 inches diameter with 6 inches stroke, and 2 feet $3\frac{1}{4}$ inches centre to centre. The wheels are $16\frac{1}{4}$ inches diameter, the frames 7 feet $4\frac{1}{4}$ inches long, and the extreme width of the engines is 3 feet. The boilers are of steel, 2 feet 3 inches outside diameter, 2 feet long between tube plates; and work at a pressure of 170 lbs. per square inch. The tractive power of the engines is about 1,400 lbs., and their weight when full and in working order 3·19 tons. The rolling stock includes locomotive-boiler trolleys, and several kinds of trucks, all built of iron throughout. The locomotive-boiler trolley consists of a pair of four-wheeled bogies connected together by a wrought-iron bar, and fitted with special arrangements for supporting the boiler. Some of the trucks have flat tops, others have deep sides, and a third class have still deeper sides and are mounted as tip trucks. (Proceedings 1888, pages 345–6.)

MANCHESTER SHIP CANAL.

The total length of the canal is $35\frac{1}{2}$ miles, from the docks in Manchester down to the entrance locks at Eastham on the tideway of the Mersey, six miles above Liverpool, Plates 91 and 92. The total fall of water-level is $60\frac{1}{2}$ feet, which is divided among four sets of locks. The first set of locks is at Mode Wheel, $1\frac{3}{4}$ miles from the terminus of the Manchester docks, and the fall here is 13 feet; the second is at Barton, $3\frac{1}{4}$ miles further, with 15 feet fall; the third is at Irlam, 2 miles below Barton, with 16 feet fall; the fourth at Latchford, $7\frac{1}{2}$ miles below Irlam, with $16\frac{1}{2}$ feet fall. This upper portion of the canal, $14\frac{1}{2}$ miles from Manchester to Latchford, will be filled with the waters of the Irwell, Mersey, and other rivers; it will in fact be a canalised river, taking the place of the Irwell and Mersey through this distance, and continuing to be, as these rivers are at present, the main drain for their watersheds in Lancashire and Cheshire. Large sluices are therefore being provided at each set of locks, for the passage of land floods and surplus water. Of the 21

miles forming the lower or tidal portion of the canal from Latchford to Eastham, the twelve miles from Latchford to Runcorn are inland; the remaining nine from Runcorn to Eastham follow the south-western shore of the Mersey estuary, the route lying mostly inland, but partly on the foreshore where necessary to cross sinuosities in the bank for obtaining a more direct course for navigation. Throughout this tidal length the water-level will be maintained at about mean high-water at Eastham, namely 14 ft. 2 ins. above the Old Dock sill at Liverpool.

The entrance locks at Eastham are being constructed for admitting vessels at almost any state of the tide; their lower sills are three feet deeper than the entrance channel, which is being dredged deep enough to give 30 feet at high water of neap tides and 40 feet on spring tides, so as to enable large vessels to navigate the entrance during a great part of every tide, and others during almost the whole time. There are three locks alongside of one another, the largest being 600 feet long by 80 feet wide, the next 350 by 50, and the smallest 150 by 30. There are also two sluices, each 20 feet wide, for assisting in filling the canal; besides which, on all tides above the ordinary level of the water in the canal, all the lock gates will be opened as soon as ever the tide rises to that level, and will be kept open till high water. Spring tides will rise from five to seven feet above the ordinary water-level in the canal.

The four sets of locks for the upper reaches of the canal will each consist of two: a larger lock 600 feet long by 65 feet wide, and a smaller 350 by 45. The minimum depth of the canal will be 26 feet, and the large lock sills are being constructed two feet deeper, in view of future deepening of the canal by dredging. All the lock gates are constructed of hard Demerara green-heart, which has been found to be exceedingly durable, and the wooden gates are less liable to damage than those made of iron. The gates will be worked by hydraulic power at each lock, the engines and machinery being constructed by Sir W. G. Armstrong, Mitchell and Co.

In the two reaches of five miles from Manchester down to Barton, the canal will be 230 feet wide at water-level and 170 feet

at bottom. Throughout the rest of the 30½ miles from Barton to Eastham, the width at water-level will average 172 feet, with a minimum of 120 feet at bottom. This width will allow of large steamers passing each other at any part of the canal. At the several locks it is widened out considerably, and will admit of vessels turning if necessary. At manufacturing works built on the sides of the canal it will be widened out so as to allow vessels to lie alongside wharves without interfering with the regular traffic up and down.

On the nine miles length along the foreshore from Runcorn to Eastham, embankments have had to be formed; where these are on sand, close piling is driven at the foot of each bank; where the foundation is rock or clay, they are made of clay hearting protected by heavy stone-work. They are generally 20 to 25 feet wide at top, with outside slopes of 1½ to 1, and inside slopes of 1 to 1. In these embankments will be constructed three weirs, each 600 feet long, for allowing the tide when above the ordinary water-level to flow into and out of the lower portion of the canal. In the embankment opposite the river Weaver are ten large sluices, each 30 feet wide, for allowing the Weaver water to flow out of the canal, and also for tidal flow. They are on Mr. Stoney's plan, working on a movable frame of rollers; and being balanced they work with great ease, requiring only slight power to lift them. Similar sluices are provided for letting off flood and surplus water from the upper reaches of the canal; there will be four alongside the locks at Mode Wheel, four at Barton, five at Irlam; but only three at Latchford, because the Mersey flood water will flow down the river channel as at present from the point where the canal leaves the river a little above Latchford.

The docks at Manchester will have a water area of 104 acres, and a quay area of 152 acres; and the length of the quays will be 5¼ miles. At Warrington a dock is proposed with a water area of 23 acres. At Partington the canal is widened to allow steamers to lie on either side. The Weaver embankment will pen the water three miles up that river to Frodsham, rendering an extensive sheet of water available for vessels of any size after it has been dredged deep enough. The large dock thus formed is joined to the Weaver

navigation by a lock 229 feet long and 42 feet wide, which will admit the Cheshire salt traffic to the canal. Large locks are being built in the embankments at Weston Point and Runcorn, for allowing coasters and barges to enter and leave the canal from and to the docks at these places. The shipping at Ellesmere Port will use the locks at Eastham. At Old Randles, above Runcorn, two sluices, each 30 feet wide, will enable tidal or river water to be let into or out of the canal.

Where railway lines cross the canal, they are being raised by high-level deviations extending $1\frac{1}{4}$ mile on each side of the canal, so as to allow a minimum headway of 75 feet; the full navigable width of 120 feet has also been maintained under the bridges. As the railway viaducts are mostly on the skew, the clear spans of their openings vary from 137 to 266 feet. Between Manchester and Runcorn are two high-level road bridges, and seven swing road bridges; the latter will be worked by hydraulic power, as will also the movable aqueduct for carrying the Bridgewater canal over the ship canal. The aqueduct will consist of a long iron caisson, turning like a swing bridge upon a central pier, with an opening of 90 feet width on each side. The water will be retained in the caisson while swinging round, and also in the Bridgewater canal, by swinging gates at each end.

The ship canal passes through either red sandstone rock or marl, overlain by alluvial deposits of clay, gravel, sand, or loam. The rock is used for pitching the slopes, where the soil is soft and requires protection from the wash of the steamers. The gravel and sand are used for concrete, of which $1\frac{1}{4}$ million cubic yards are required. Concrete is used wherever practicable in dock and lock walls. The copings and hollow quoins are of Cornish granite; hard sandstone and limestone are used for other portions. The total amount of brickwork, which is all faced with blue bricks, is 175,000 cubic yards, requiring nearly 70 million bricks; and there will be 220,000 cubic yards of masonry. The lower portions of the dock and lock walls are formed of concrete, which is protected at the water-level by granite or limestone fender courses projecting slightly from the face of the wall. Above these courses the concrete

walls are faced with brickwork. In the upper portions of the dock walls are built culverts for hydraulic and gas mains.

The deepest cutting is 66 feet deep, for a short distance near Runcorn. The largest cutting averages 55 feet depth for a length of 1½ mile near Latchford. The slopes of the cuttings vary between 1 to 1 and 2 to 1, except in the rock cuttings, where the sides are nearly vertical. The total amount of excavation in the canal and docks amounts to about 46 million cubic yards, of which 10 million is in sandstone rock. The spoil is used for filling up river bends which are cut off by the canal, and for raising adjacent low-lying lands. (See also Mr. E. Leader Williams' paper, pages 418–427.)

LAKE VYRNWY.

Lake Vyrnwy, the new source of water-supply for Liverpool, is situated in Montgomeryshire, North Wales, 10 to 15 miles from Bala station, and 9½ to 14½ miles from Llanfyllin station, Plates 104 and 105. The lake has been formed by building a masonry dam across the valley of the river Vyrnwy, a tributary of the Severn, near its narrowest part. The site was chosen not for this reason alone, but also because the rock beneath the alluvium at this part of the bottom of the valley was found to have formed in past ages the natural bar or dam of a post-glacial lake, subsequently filled up by the alluvial deposit brought down by the streams above. A trench 1,100 feet long, 120 feet wide, and 60 feet below the alluvial surface at the deepest place, was made right across the valley down to the rock forming the ancient natural bar. All the loose silt, gravel, and boulders were removed, and the sloping rock was stepped so as to form a secure foundation for the base of the masonry dam; and the river Vyrnwy, which flowed through the valley, was diverted and carried over the excavation.

When the lake is full to the overflow, the surface is 825 feet above sea-level, and the principal dimensions are:—superficial area 1,121 acres; length 4¾ miles; average width ½ mile; maximum depth 84 feet; capacity 13,125 million gallons. The area of the

present gathering ground is 18,000 acres, which the Corporation have power to increase to 23,200 acres by diverting two other streams. It is estimated that the rainfall will then yield an average daily supply of at least 53 million gallons, of which 40 million gallons will be available for Liverpool after delivering the required compensation water to the river below the dam. The length of the road round the margin of the lake is nearly 12 miles, including the road over the dam.

Masonry Dam.—The dimensions of the dam are as follows :—total length along carriage way 1,165 feet, or 0·22 mile; height of parapet above bottom of foundation 161 feet; height from river-bed to sill of overflow 84 feet; greatest head of water at base of dam 146 feet; greatest thickness at base 120 feet; width of roadway between parapets 19·8 feet; batter of wall, inside 1 horizontal in $7\frac{1}{4}$ vertical, outside 1 horizontal in $1\frac{1}{2}$ vertical; total quantity of masonry 260,975 cubic yards, or 510,000 tons. The dam is built of hard dark grey stone commonly known as "clay slate," from the lower silurian formation, obtained from a quarry situated about $1\frac{1}{4}$ mile north, up the valley of the Cynon stream. The masonry is coarse rubble; some of the stones weighed as much as 10 tons, and more than one-third of them weighed over 4 tons. The roadway over the dam is carried on thirty-one elliptical arches of 24 feet span. The carriage way is 14 feet above the top of the dam, which itself forms the sill of the overflow from the lake; the surplus water flows through the central nineteen arches of the roadway, and down the outer slope of the dam.

Compensation Water.—The daily compensation water to the river is discharged through an 18-inch pipe laid in an outlet tunnel through the dam at the natural ground-level. A continuous daily supply of 10 million gallons is discharged in this way. Every year also, at times appointed by the Severn Commission, 1,280 million gallons have to be delivered into the river in the form of freshets, each of 40 million gallons per day for four days in each of eight months, which are discharged through a 30-inch pipe laid alongside the 18-inch pipe. The compensation water is measured in a building near the discharge pipes. The exact size of the orifice by which the flow is measured

was determined by a permanent gauging basin, which may be used at any time.

Vyrnwy Tower.—The entrance to the Liverpool aqueduct is about three-quarters of a mile from the dam, and in 50 feet depth of water. The tower containing it stands 104 feet above the surface of the lake, and is approached from the road by a causeway carried on four arches. Its internal diameter is 30½ feet. The valves by which the water is drawn in from the lake are of novel construction. Within and without the tower are two standpipes connected at the bottom beneath the foundation of the tower. Each length of pipe forming either standpipe has gun-metal faces, and is not connected with its neighbours above or below. By hydraulic pressure the lengths above any joint may be lifted. The water flows through the annular space, and may thus always be drawn through the joint nearest to the surface of the outside water, and discharged through that nearest to the surface of the inside water. By this means the best water is obtained, and the water about the strainers is not disturbed. Inside the tower the water is strained through screens of fine copper-wire gauze, to cleanse it from impurities held in suspension. When a screen gets clogged it is raised by hydraulic pressure, and automatically cleansed in a thorough manner by thin vertical revolving sheets of water from a peculiarly constructed turbine. An automatic signal-bell gives notice when a screen gets clogged. The hydraulic machinery in the straining tower is worked by pumps driven by water from a small reservoir on the adjoining hillside.

Aqueduct.—The distance along the aqueduct from the lake to the Town Hall, Liverpool, is 76 miles. It consists for the most part of cast-iron socket-pipes varying from 39 to 42½ inches inside diameter, and from 1 to 2¼ inches thick. The pipes are made in 12-feet lengths, and are jointed with lead. For about four miles the water flows through three tunnels; and in some specially important places, such as river crossings, through mild-steel pipes.

NORTON WATER TOWER.

This tower carries the last of five balancing reservoirs on the aqueduct between Lake Vyrnwy and the old Prescot reservoirs, eight miles from Liverpool. It is situated at Norton, near Runcorn, about 17 miles along the aqueduct from Liverpool, Plate 104. As the ground is here more than 100 feet below the hydraulic gradient, a tower had to be constructed for raising the tank to the required level. The structure is of Roman Doric design, built of the new red sandstone of the district; its height to the top of the tank is 113 feet, and its diameter at the base is 95 feet. The tank is supported without girders or columns; cast-iron bed-plates resting upon the circular cornice of the masonry support by means of a hard steel expansion-joint a hoop of riveted steel plates of the same diameter as the tower, designed to resist compression towards its centre. The bottom of the tank is constructed entirely of mild-steel plates, riveted together in the form of a segment of a sphere; the vertical sides are of cast-iron. The principle is that of an inverted dome under tension, and no internal supports are required. The capacity of the tank is 651,000 gallons of water.

MATERIALS FOR THE STUDY OF STEEL AND OF STEEL GUNS.

By D. CHERNOFF.

Translated by Dr. William Anderson, F.R.S., Vice-President; and published by the authority of the Council.

[The following remarks, made by the author in the discussion on 23 Nov. 1868 upon his paper "On the Manufacture of Steel, and the mode of Working it," have been translated from the Proceedings of the Imperial Russian Technical Society, having been accidentally discovered only recently by the translator, by whom the loan of a rare copy was procured with some difficulty.]

Mr. Chernoff reviewed the principal points raised in his paper "On the Manufacture of Steel, and the mode of Working it" (Proceedings Inst. Mech. E. 1880, page 286), and expressed his opinion that the tenacity of the same piece of steel varied between very wide limits depending on the structure of the specimen; and that, if it were desired to compare two samples of steel, the comparison should be made only when it was certain that the two specimens were in the same condition with respect to internal structure. The more a crystalline structure predominated, the less tough would the steel be, and the lower would be its quality. In addition, he expressed his opinion that the tenacity of a piece of steel of given internal structure would be the same, by whatever means that structure was obtained, whether by forging or otherwise. The greater or less extent to which crystals are developed depends upon the slower or quicker rate of cooling of the steel from a temperature higher than that at which it changes to the amorphous structure; and also upon the greater or less nearness with which that higher temperature approaches the point of fusion.

In support of these conclusions, Mr. Chernoff referred to the results which he had obtained in the testing of various samples of steel; and he submitted two additional specimens prepared from the same piece of steel in the following manner. A round bar, $3\frac{1}{4}$ inches diameter by 8 inches long, was heated uniformly to a bright red (orange) heat, and was then reduced by forging throughout its length to $1\frac{1}{2}$ inch diameter; the forging was completed while the steel was still at a light red heat, and the bar was allowed to cool gradually in dry sand. When cold it was broken in two, and one half was treated in the following manner. It was heated to a temperature a little higher than *b* on Chernoff's scale, Fig. 1, Plate 106 (see also Proceedings 1880, page 290); in this scale *b* is the temperature below which if steel be heated it does not change its structure in cooling, whether cooled slowly or quickly. The heated piece was then at once plunged into water, from which it was withdrawn at a dull red heat, and allowed to cool in dry sand. Specimens were then cut from each half of the original bar, and tested for tensile resistance.

The first specimen, from the forged but untreated half, was 5·8 inches long by 0·8 inch diameter; the load first applied was 4,680 lbs., and was increased by twelve increments of 3,120 lbs. up to 42,120 lbs., which was safely carried; but when the next increment was added, the specimen broke, having stretched uniformly throughout its length. Assuming that the load of 42,120 lbs. finally carried without breaking indicated the ultimate strength, this would amount to nearly 38 tons per square inch, with an elongation of 7·07 per cent.; and the dynamic resistance of a cubic inch was about 1·3 inch-tons.

The second specimen, taken from the forged and treated half of the bar, was 6·3 inches long by 0·8 inch diameter. The loading being carried out in the same way as with the first specimen, 57,720 lbs. were lifted safely, and the specimen broke asunder at the next increment. Just before fracture a contraction took place about the middle of the length of the specimen. Supposing that 57,720 lbs. was the ultimate strength, this is equivalent to 52 tons per square inch. The elongation was 7·7 per cent., and therefore the dynamic resistance per cubic inch was nearly 2 inch-tons.

On the strength of these and similar investigations, Mr. Chernoff proposed to try, on a 4-pounder gun, the principle of bringing steel to the amorphous condition and then cooling it quickly down to a certain point, hoping by this means to increase its resisting power; and thus to enable a lot of 4-pounder guns, which had been rejected for insufficient strength, to pass proof satisfactorily. In order to form an estimate of the probable effect of this treatment, he communicated the results of some former experiments with the 4-pounder guns.

Muzzle-loading guns Nos. 24 and 44, 3·37 inches calibre, 7·85 inches external diameter, steel shot about 12½ lbs. weight, windage 0·03 inch:—

Gun No. 24.	Gun No. 44.	Charge.
2 rounds.	1 round.	1·35 lbs.
1 „	2 „	1·8 „
2 „	1 „	2·7 „
Gun burst.	Gun burst.	

As it was thought that the smallness of the windage was the chief cause of the destructive effect of a 2·7 lbs. charge, the proof of the further guns was made with cast-iron shot about 12·15 lbs. weight, surrounded with zinc bands, 3·2 inches diameter.

Gun No. 28.	10	rounds,	1·35 lbs. charge.	
	5	„	1·8 „	
	5	„	2·25 „	
	1	„	2·475 „	Gun burst.

Before the final boring out, this gun had been hardened by means of cold water inside the bore; but in the hardening no attention had been paid to Mr. Chernoff's investigations, and to the essential principles involved in the process: that is, the temperature *b* had not been reached in the heated steel. The treatment had actually injured the material, inasmuch as the gun did not withstand even the 2·475 lbs. charge; and, as Mr. Chernoff supposes, had not merely left the original coarsely crystalline structure, but had added to it a certain degree of hardening which still further reduced the tenacity.

Gun No. 135.	1	round,	1·35 lbs. charge.	
	1	„	1·8 „	
	1	„	2·25 „	
	1	„	2·475 „	
	10	„	2·7 „	Gun burst.

Gun No. 138. The external diameter was made 1 inch larger than that of the others:—

1	round,	1·35	lbs. charge.
1	„	1·8	„
1	„	2·25	„
1	„	2·475	„
6	„	2·7	„

In consequence of the considerable increase in the diameter of the bore, the experiment was stopped.

Gun No. 142.

1	round,	1·35	lbs. charge.
1	„	1·8	„
1	„	2·25	„
1	„	2·475	„
2	„	2·7	„
1	„	1·8	„
2	„	2·25	„
1	„	2·7	„

The experiment was stopped on account of the enlargement of the bore by $6\frac{1}{2}$ hundredths of an inch.

Gun No. 139.

1	round,	1·35	lbs. charge.	
1	„	1·8	„	
1	„	2·25	„	
1	„	2·475	„	
6	„	2·7	„	Gun burst.

Gun No. 56 before finishing was annealed and hardened:—

1	round,	1·35	lbs. charge.	
1	„	1·8	„	
1	„	2·25	„	Gun burst.

The fractured surfaces showed that the temperature *b* had not been reached; while the boring out proved that the temperature *a* had been exceeded, as it had been in gun No. 28, because the material had hardened. The temperature *a* on Chernoff's scale is below *b*, and is such that steel, however hard it may be, will not harden if heated to a temperature lower than *a*, however quickly it is cooled, Fig. 1, Plate 106.

Gun No. 6. The breech had been strengthened by means of three steel hoops, shrunk on with a shrinkage of 0·03 inch:—

2	rounds,	1·35	lbs. charge.
2	„	1·8	„
1	„	2·25	„
1	„	2·475	„
6	„	2·7	„

Further proof was stopped because the bore had enlarged by 6 hundredths of an inch, and the first ring from the breech end had cracked and opened 1-8th inch.

Guns Nos. 18 and 21 were handed over to Mr. Chernoff to treat as he pleased. They were heated to a temperature rather higher than *b*, and then quickly cooled to a temperature lower than *b*, and then allowed to cool slowly in dry sand. Firing proof gave the following results.

Gun No. 18, outside diameter 7·85 inches, diameter of bore 3·41 inches, diameter of shot 3·2 inches; the windage round the body of the shot was therefore somewhat greater than in the rest of the guns, but on the other hand the bands which encircled 0·63 of the circumference of the shot had the same amount of windage as in the other guns :—

5	rounds,	1·35	lbs. charge.	
1	„	1·8	„	
1	„	2·25	„	
1	„	2·475	„	
21	„	2·7	„	
1	„	3·15	„	
20	„	3·6	„	
5	„	3·6	„	double shotted.

The diameter of the bore at a distance of 50 inches from the muzzle had increased by $4\frac{1}{4}$ hundredths of an inch.

Gun No. 21, external diameter 7·75 inches, bore 3·364 inches :—

1	round,	1·35	lbs. charge.	
1	„	1·8	„	
1	„	2·25	„	
1	„	2·475	„	
21	„	2·7	„	
1	„	3·15	„	
20	„	3·6	„	
5	„	3·6	„	double shotted.

The diameter of the bore at a distance of 50 inches from the muzzle had increased by $5\frac{1}{8}$ hundredths of an inch.

Mr. Chernoff exhibited several specially prepared specimens intended to illustrate characteristic periods in the working of steel: as for example, several specimens of cast but unforged steel, of which one specimen was especially remarkable for the strong development of a crystalline structure, arising from very slow cooling in the crucible inside the furnace; also a specimen of unforged steel of crystalline structure, and a fragment of the same piece in which the amorphous condition had been preserved by rapid cooling, the fracture appearing in consequence finely crystalline. Several specimens of forged cast-steel were also shown.

Mr. Chernoff explained that his process had been carried out with a furnace of special construction, shown in section in Fig. 2, Plate 106, into which the gun was let down in a vertical position by a crane, and deposited on its breech end upon an annular chair C. The furnace was itself sunk in the ground near the crane, and had an annular grate G at bottom, with an aperture A for firing and for setting the breech of the gun in its place upon the ring R on the top of the chair C. Numerous sight-holes S enabled the progress of heating to be watched. The flue F passed off to the chimney; and a sheet-iron cover V closed the top of the furnace while in operation. Before receiving the gun, the furnace was heated to redness; while the gun also was gently warmed beforehand, till it had attained a temperature of about 300° C. or 572° Fahr. at the breech end. The gun was then lowered into the furnace, and raised to a red heat; and was then withdrawn, and lowered, still in a vertical position, into an iron tank O, Fig. 3, filled with olive oil. The oil tank was itself immersed in a larger tank W, through which a current of cold water was made to circulate from the inlet pipe I at bottom to the overflow trough T at top. The gun did not remain in the oil more than half a minute, so as to avoid too rapid cooling and consequent hardening, the object being merely to reduce the steel to a temperature below *b*, and by that means to retain its amorphous

structure. The gun came out of the oil at a dark red heat, and was buried in dry sand in order that it might cool slowly, so as to avoid internal stresses; the cooling might safely be slow, because below the temperature *b* steel is incapable of undergoing any molecular change. In order to permit the oil to circulate through the bore while the gun was submerged in the oil tank, Fig. 3, the breech end had drilled through it axially a hole $2\frac{1}{4}$ inches diameter, which was afterwards closed by a cascable screw.

Mr. Chernoff added some remarks on the forging of steel, and the effects which he considered were produced by the process. The necessity for forging an ingot of gun steel arose from the circumstance that it was not as yet known how to make sound steel castings. The castings usually had internal cavities arising from contraction, and on their external surfaces were formed an immense number of gas bubbles, which constituted a porous envelope. It was consequently necessary to cast the ingot much shorter and thicker than required for the gun, and then to close up the cavities and draw them out under the hammer. By this operation the internal hollows as well as the external porosities became elongated and attenuated, so that it was easier to remove them by subsequent boring and turning. It might therefore be said that forging would have to be retained, until it had been learnt how to produce absolutely sound castings.

MEMOIRS.

Henry John Card Anderson was born at Salisbury on 2nd March 1835. At the age of sixteen, with a view to the engineering profession, he was articled for three years to Mr. F. Rumble. On the completion of his pupilage he became a draughtsman in the office of Mr. Thomas Page, by whom he was engaged on the works of the new Westminster Bridge. He was next employed by Mr. Joseph Cubitt on the Rochester Bridge works of the East Kent Railway. In 1859 he went to Bombay to occupy a post on the Great Indian Peninsula Railway; but a severe sunstroke necessitated his return in the following year. Afterwards he was employed as resident engineer for Mr. Cubitt and Mr. W. M. Brydone on the Aylesbury and Buckingham, the March and Spalding, and the Stamford and Gibson railways. After the completion of the works on these lines he entered the service of Messrs. Easton Amos and Anderson, and acted as resident engineer in the construction of the Lade Bank pumping station of the River Witham drainage. In 1868 he was similarly employed during the building of the iron pier at Grays, Essex, for the Grays Chalk Quarries Company; and later in the same year went to Egypt to erect the Boulac paper mills for Messrs. Easton. During 1870–72 he built the three large sugar factories of Aba, Beni Mazar, and Salagoss, and superintended their working until 1876, when he constructed the Gizeh pumping station for supplying water to the palaces and gardens in that suburb of Cairo. Till 1879 he was employed in the management of the Khedive's sugar factories, and during part of that time acted as resident agent in England. In that year he became chief assistant to Mr. Edward Easton, and his representative in Egypt, and in 1880 became his partner, and carried out many large

works connected with water supply, including the large pumping station at Katatbeh. The partnership being dissolved in 1882, he then formed a small company, which entered into contracts with the Egyptian government for cleaning, widening, and deepening by mechanical means the irrigating and draining canals of the Delta. His knowledge of the country, and of the ways and language of the people, enabled him to aid materially in suppressing forced labour, and in performing the important work of maintaining the Delta canals by the means ordinarily employed in other countries. His health, having become enfeebled by sunstroke and long exposure in a tropical country, gradually broke down, and he died on 25th March 1891, at the age of fifty-six. He became a Member of this Institution in 1876.

Captain Charles Fairholme, R.N., was born at Brussels on 5th December 1829, being the son of Mr. G. Fairholme of Greenknowe, Berwickshire. Entering the royal navy in 1842, he served with distinction throughout the war in the Crimea, first as lieutenant in the "Agamemnon," then as naval aide-de-camp to the general commanding-in-chief during the siege and capture of Sebastopol, and afterwards in the "Medusa," during the final operations in the Sea of Azof. He commanded the gunboat "Havoc" at the capture of the Peiho forts, and in other operations in China in 1860. Not long after his retirement from naval service he became interested in the Heberlein self-acting railway brake, which he further improved; and he formed and successfully managed a company for working it in this country and abroad. He was thus led to take up various other inventions connected with railway engineering. He introduced into England and the colonies the Abt system of mountain railways, and succeeded in getting it adopted on a number of lines; and lately he became the representative of the Lindner starting gear for compound locomotives, of which he gave a description to this Institution in January 1890 (Proceedings, pages 84–86). His death took place at West Kensington on 11th October 1891, at the age of sixty-one. He became an Associate of this Institution in 1883.

DAVID GREIG was born at Harvieston, near Stonehaven, Kincardineshire, on 27th October 1827. In early life he assisted his father in farming in the north of Scotland; and it is somewhat remarkable that a man without any previous mechanical training should have been able to grasp the numerous branches of mechanics with which he afterwards associated himself. When quite a young man he undertook the management of a large estate in Ireland; and while superintending operations in Hainault Forest in 1858 he was engaged by Mr. John Fowler to assist him in overcoming the difficulties connected with the construction of the steam plough, the idea of which had occurred to Mr. Fowler in connection with his own draining plough and Mr. Fisken's plough driven by water power. About this time Mr. Greig introduced his well-known and valuable improvement upon the "balance plough," which is now in every-day use: the original balance plough had two straight wooden beams extending the whole length of the implement, between which the balance plough worked; and his improvement consisted in making the present form of iron balance plough-frame, which did away with the old wooden frames entirely. The Steam Plough Works having been started about 1860 at Hunslet, Leeds, by Messrs. John Fowler and Co., he then acted as outside manager and travelled to secure orders, and in this capacity he made the steam plough a commercial success. The works originally gave employment to only about one hundred men, and were limited to the production of ploughs, anchors, and engines; they now cover 8½ acres and employ about 1,600 men. During the American civil war in 1862–3 the cultivation of cotton in Egypt was carried on upon a large scale; and for the speedy preparation of the lands for this purpose the steam plough became a necessity. Mr. Greig went to Egypt, where he remained for some time; and the numerous orders received from that country contributed largely to build up the works to their present size. On the death of Mr. Fowler in 1864 (Proceedings 1865, page 14), he became a partner; and while the improvement of the steam plough and its adaptation to various kinds of work continued to receive his closest care, he also turned his attention to the manufacture of locomotives, and found uses to

which the steam ploughing engine with slight modifications could be adapted; and the employment of portable and semi-portable engines for all sorts of mining purposes was to a great extent the result. As an instance, on his advice an ordinary ploughing engine was used by Messrs. Bell Brothers of Middlesbrough for a new pit they were then sinking at the Cliff Mines near Saltburn; and it is believed this lifted many hundred thousand tons of ironstone at a cheaper rate per ton than any other engine had ever done. The introduction of this class of machinery naturally resulted in his attention being directed to all other descriptions of machinery required for mining operations, and the firm entered largely into the manufacture of all classes of mining machinery; he took the principal part in the design and manufacture of some of the largest winding engines working in this country. The success of the compound principle for marine engines led him to consider its adaptability to agricultural and stationary machinery. At the Steam Plough Works he constructed the first compound semi-portable engine; and as the experiments made with it proved successful, the manufacture of compound ploughing and traction engines soon followed. The first of the compound traction engines was exhibited at the Royal Agricultural Society's meeting held at Derby in 1881, since which date nearly all the principal agricultural firms have commenced their manufacture. He became a Member of this Institution in 1865, a Member of Council in 1878, and a Vice-President in 1886. In 1865, in conjunction with Mr. John Fowler, he contributed a paper on the application of steam power to the cultivation of land; and in 1879, in conjunction with Mr. Max Eyth, he gave another on the use of iron and steel in high-pressure boilers. He also read numerous papers on agricultural subjects before various Chambers of Commerce and other societies in different parts of the country. He took an active part in the Iron Trades Employers' Association, of which he was the president for two years, 1881–82 and 1882–83. He was a life governor of the Yorkshire College, and a member of its Council; and was one of the representatives of the engineering trade on the Council of the Leeds Chamber of Commerce. He was also a justice of the

peace for the borough of Leeds, and for many years took a keen interest in local affairs. He died at his residence, Leeds, on 20th March 1891, at the age of sixty-three, after a lingering illness.

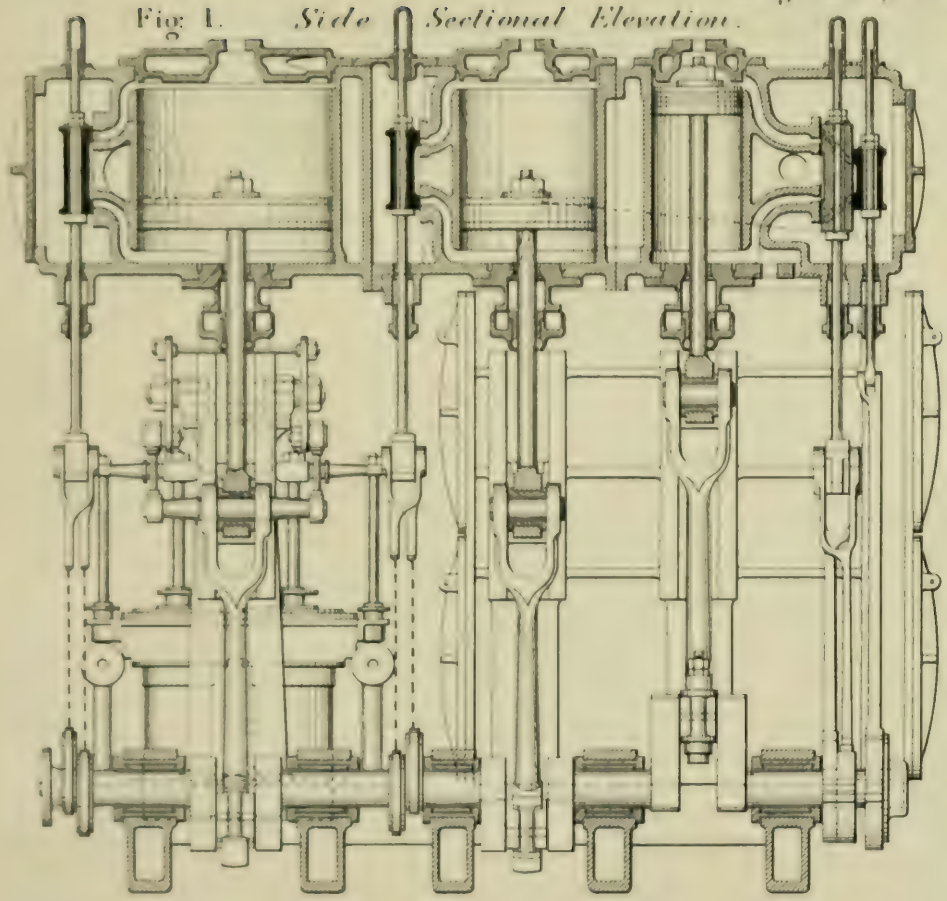
JOHN SEDDON was born at Westhoughton, near Bolton, on 3rd May 1816, and served his apprenticeship with Messrs. Hargreaves of Bolton, mainly on the old Bolton and Kenyon Railway. From there he went to London, and was appointed a carriage and wagon superintendent on the London Brighton and South Coast Railway, which situation he left to take charge of the railway carriage works of Messrs. Finch and Willey, of Liverpool. In 1851 he went to Wigan, and became agent for Lancashire, Wales, and Scotland, on behalf of the Metropolitan Railway Carriage and Wagon Co. In 1874 he initiated the Wigan Wagon Works; and he was also a director of the Ince Hall Rolling Mills Co. For some years he was a member of the Wigan Town Council, and in 1885 was placed on the commission of the peace. Having been in failing health for some time, in returning recently from Harrogate he had to be taken to his son's residence at Hindley, near Wigan, where he died on 3rd October 1891, in the seventy-sixth year of his age. He became a Member of this Institution in 1864.

RICHARD SENNETT was born near Penzance on 25th October 1847. In 1862 he entered Keyham Factory, Devonport, as an engineer student, and after serving five and a half years there in this capacity was selected to proceed to South Kensington for the more advanced course of training given at the Royal School of Naval Architecture, at the conclusion of which he obtained the highest diploma and a first-class fellowship. He subsequently became instructor in marine engineering at the Royal Naval College, Greenwich, and obtained a Whitworth scholarship. After service at sea as engineer, he was appointed in 1872 to the Admiralty for scientific work; and in 1875 proceeded to Devonport Dockyard as assistant to the chief engineer. After serving there for about eight years he returned to the Admiralty, and in 1883 succeeded Mr. John Oliver as chief engineer inspector, attaining the naval rank of inspector of

machinery in 1885. On the retirement of Sir James Wright in May 1887, he was appointed Engineer-in-Chief at the Admiralty, which position he held until May 1889, when he resigned the appointment and his rank in the navy, and became managing director in the firm of Messrs. Maudslay Sons and Field. He was the author of a standard work on the marine engine, which has been translated into Russian and Italian. His death took place on 4th September 1891 at Walton-on-Thames, at the age of forty-three. He became a Member of this Institution in 1881; and was a Vice-President of the Institution of Naval Architects.

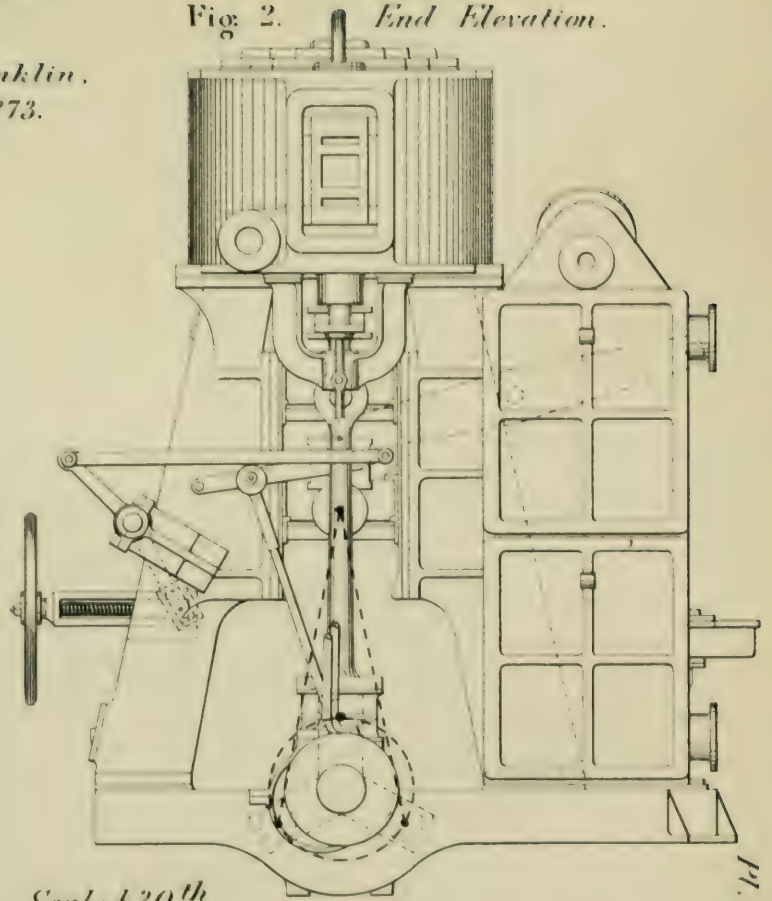
Engines of the "Sexta".

Fig. 1. *Side Sectional Elevation.*



Franklin, 1873.

Fig. 2. *End Elevation.*



Scale 1/30th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

Mechanical Engineers 1891.

Pl. 60.

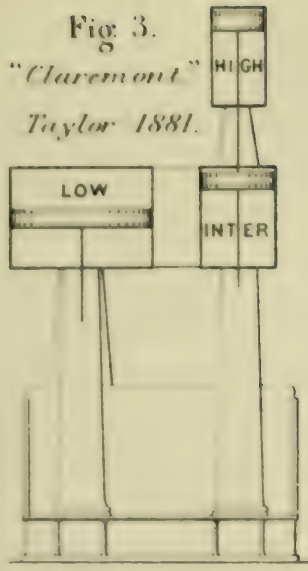


Fig. 3.
"Claremont"
Taylor 1881.

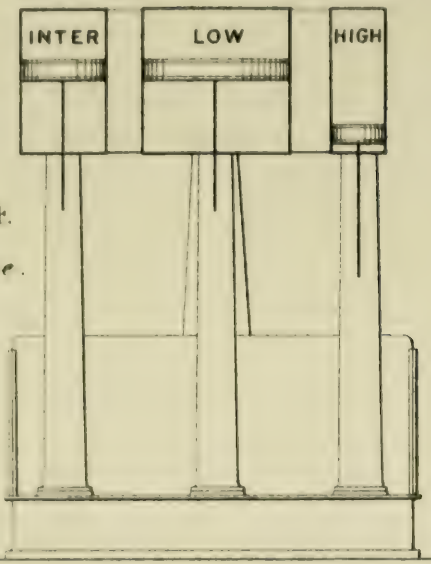


Fig. 4.
Wyllie.

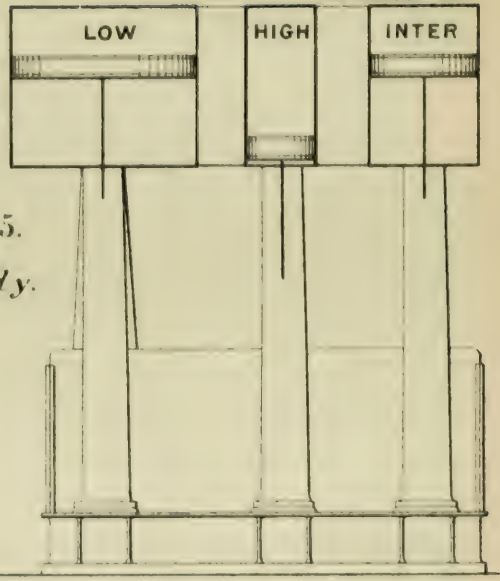


Fig. 5.
Tweedy.

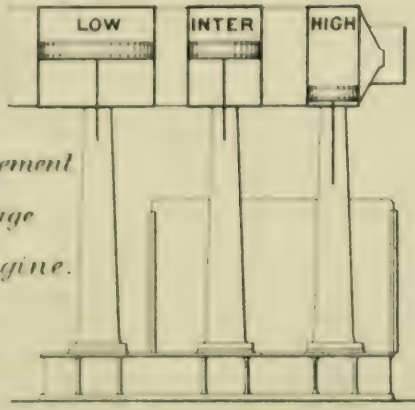


Fig. 6.
Earliest arrangement of Three-stage Expansion Engine.

Mechanical Engineers 1891.

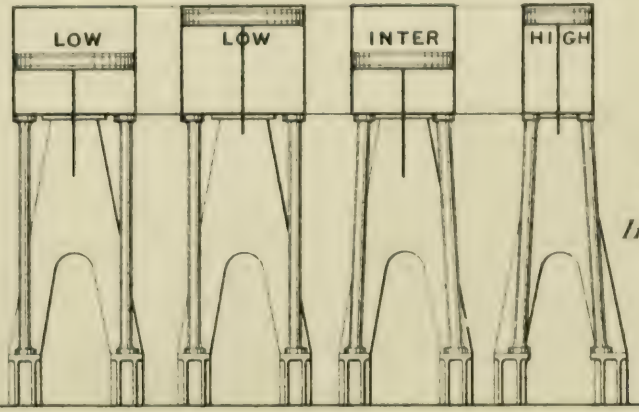


Fig. 7.
Humphrys.

Earle and others.

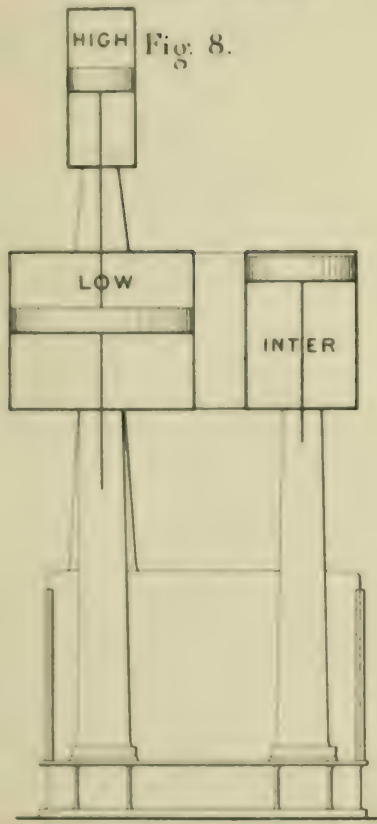


Fig. 8.

High-pressure Cylinder divided.

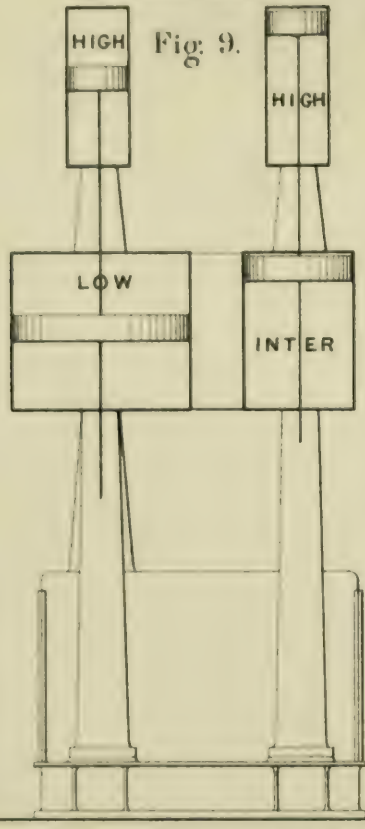


Fig. 9.

Intermediate Cylinder divided.

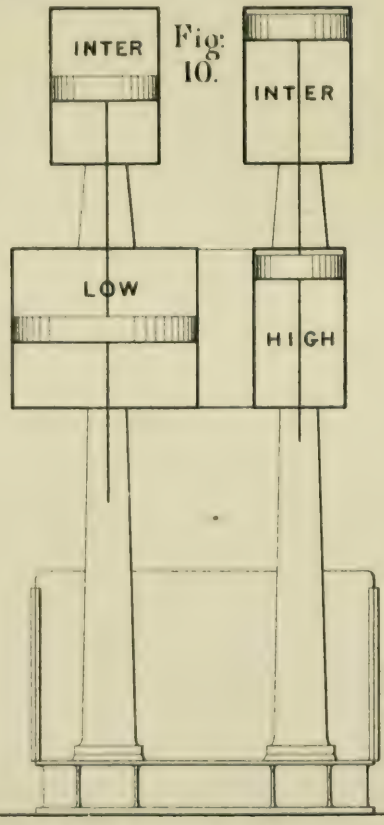


Fig. 10.

Fairfield, Glasgow.

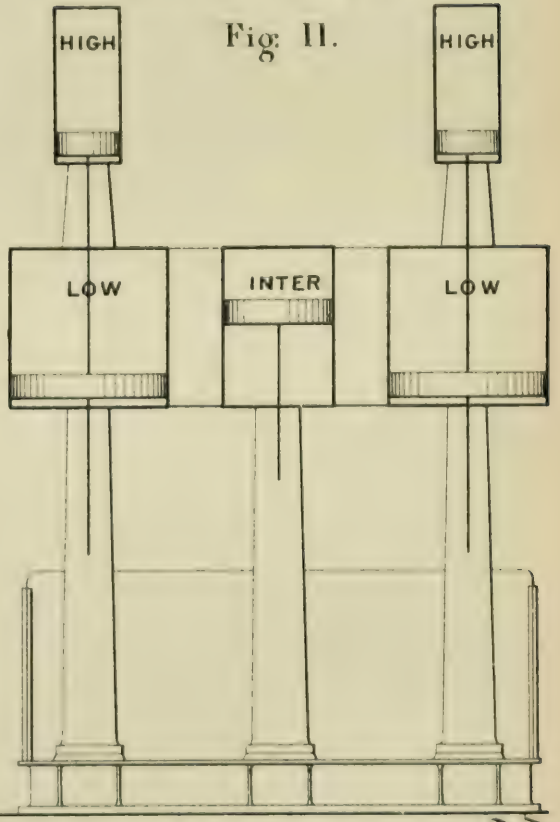


Fig. 11.

Mechanical Engineers 1891.

Pl. 62.

Rodger's Oscillating Engine.

Fig: 12. *Plan.*

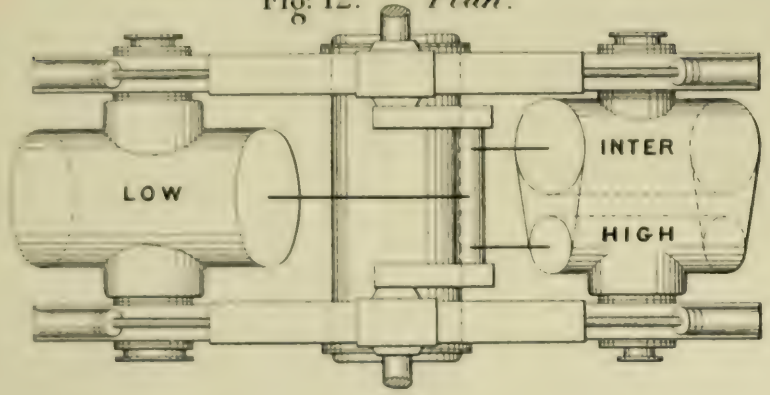


Fig: 13. *Elevation.*

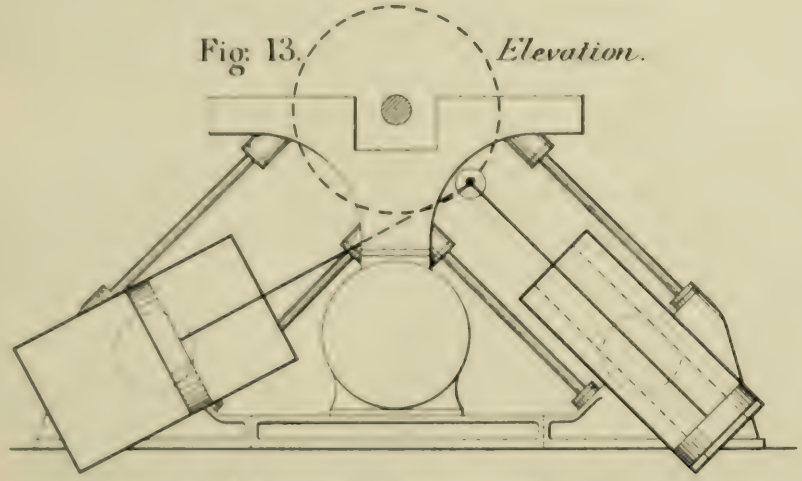


Fig: 14. *Plan.*

Piston-Valve Sleeve.

Fig: 15. *Joint.*

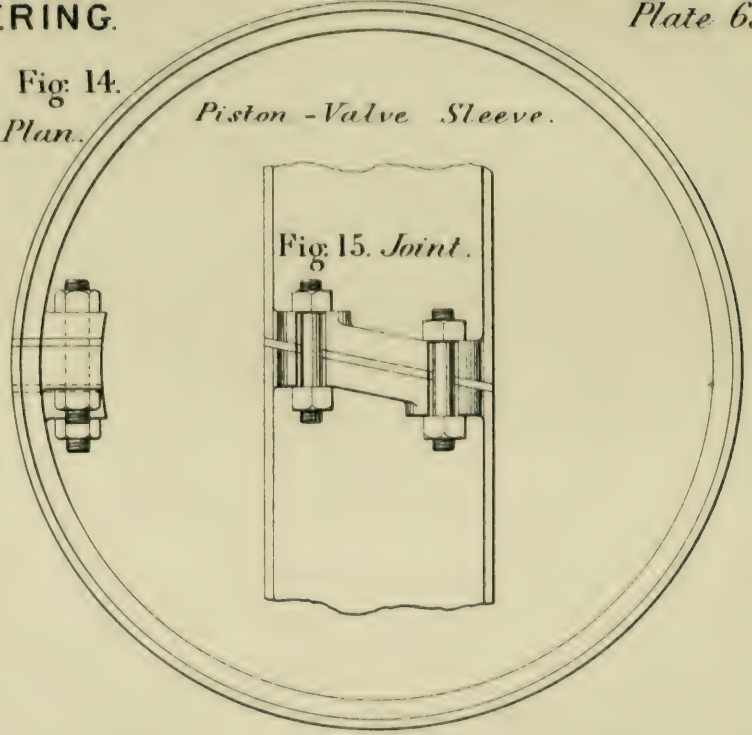
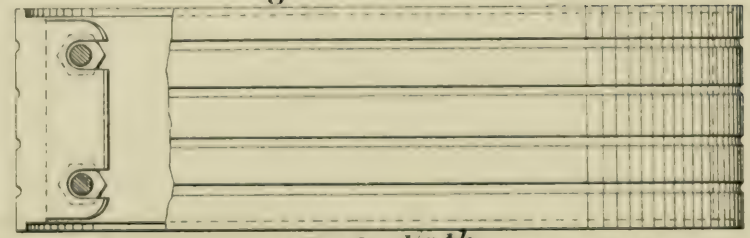


Fig: 16. *Elevation.*



Scale 1/8th

Mechanical Engineers 1891.

Plate 63.

Fig. 17. *Denny and Barrow.*

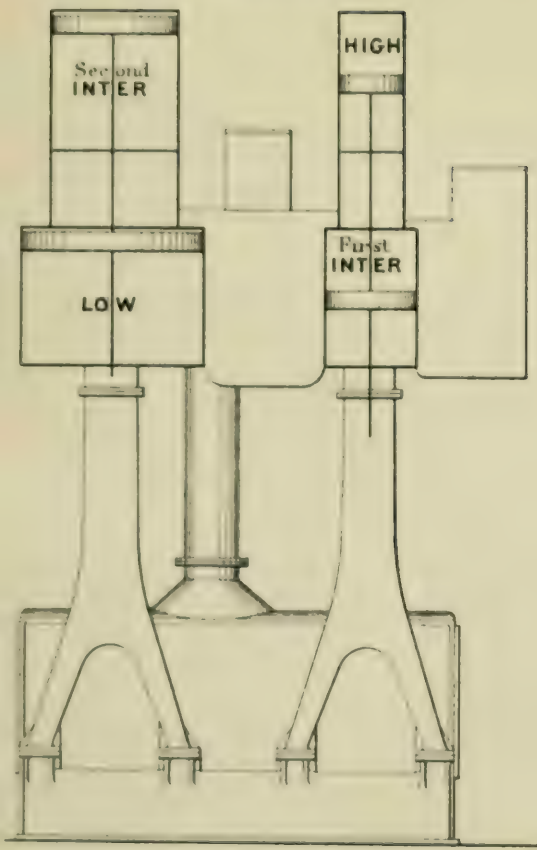


Fig. 18.

Richardson.

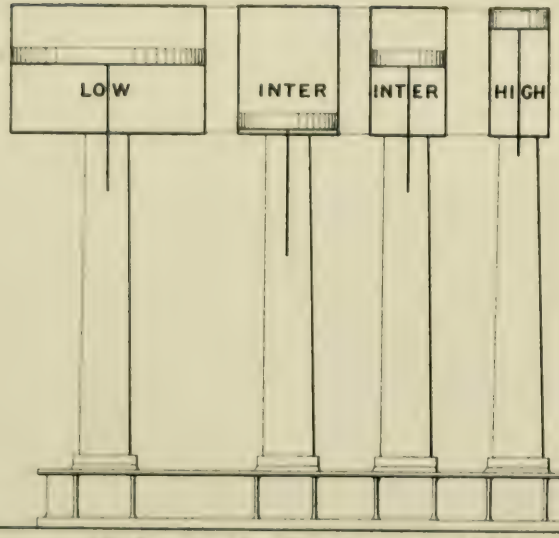


Fig. 19.

Bernays.

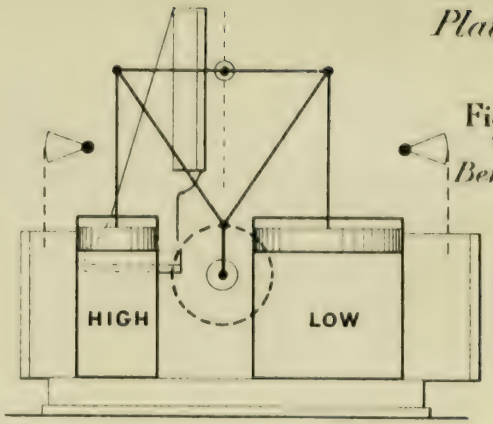


Fig. 20.

Fleming and Ferguson.

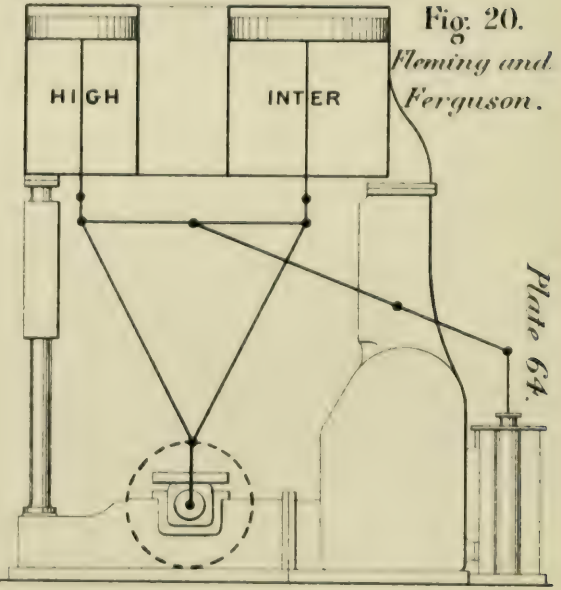


Plate 64.

"Empress of India". Starboard Engine.

Fig. 21. "Boma."

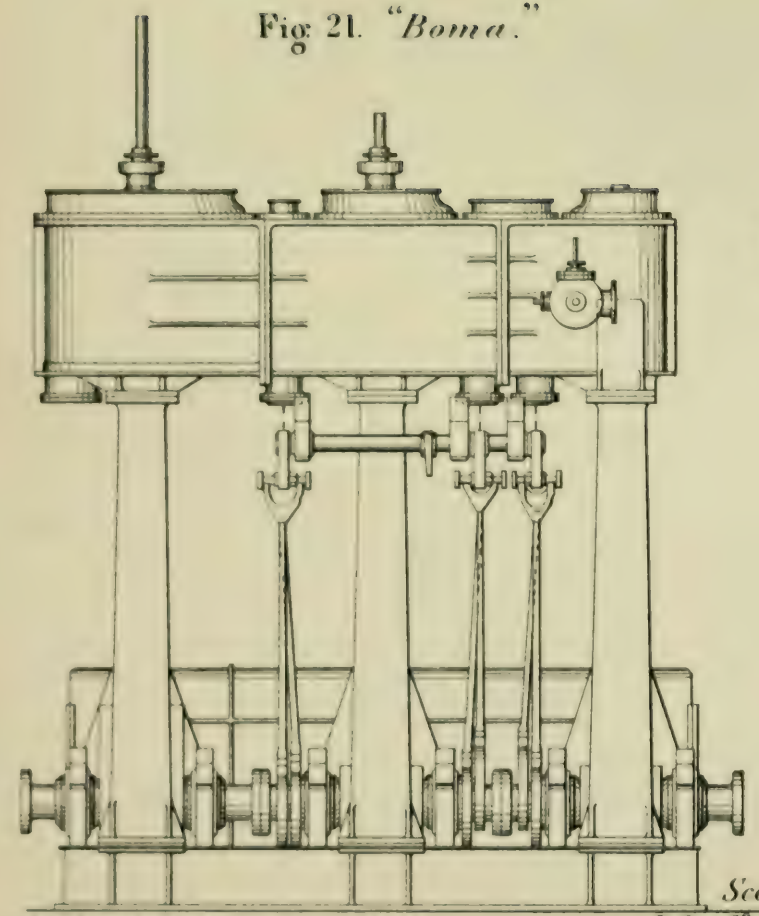
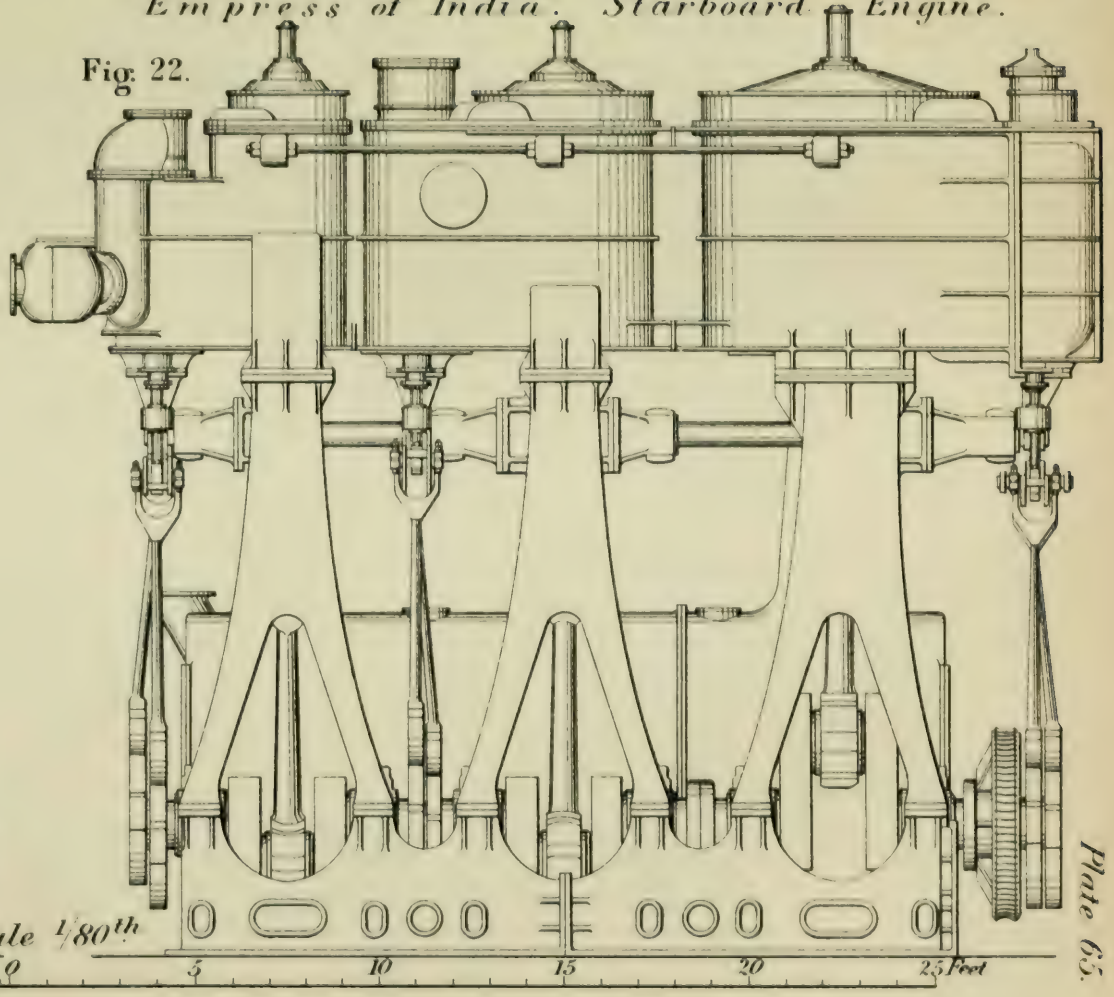


Fig. 22.

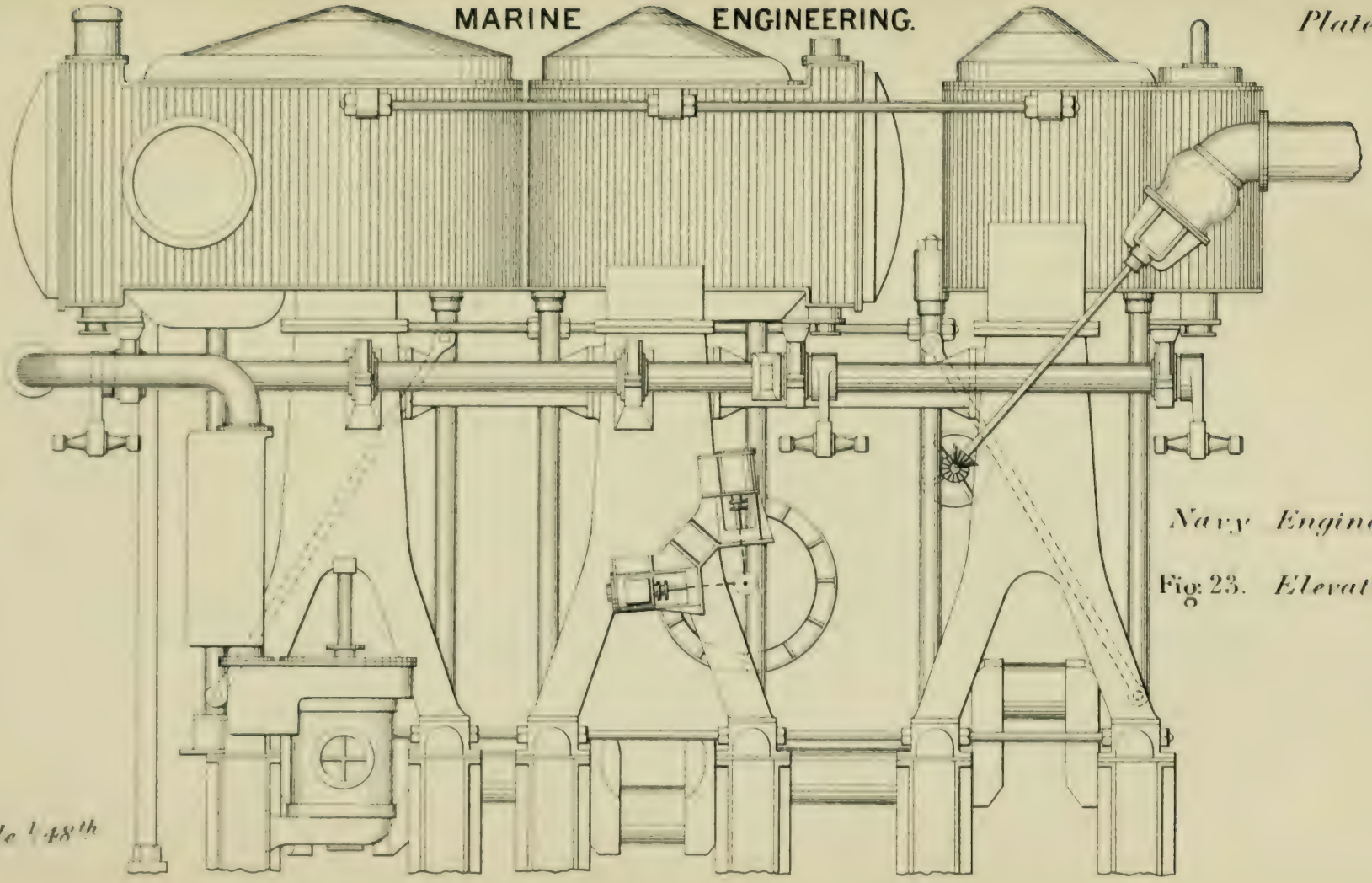


Scale 1/80th

Inches 12 0 5 10 15 20 25 Feet

Mechanical Engineers 1891.

Plate 65.

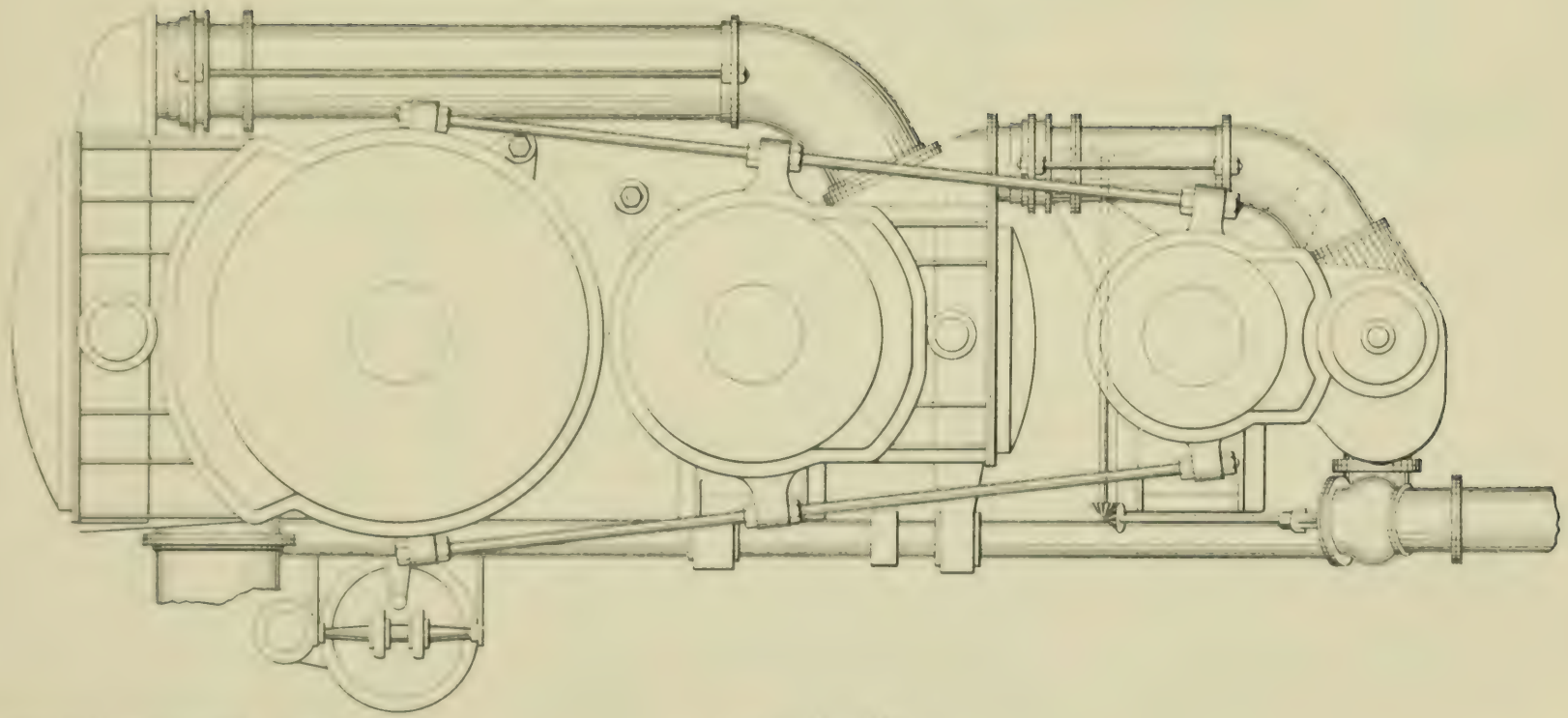


Navy Engines.

Fig. 23. *Elevation.*

Scale 1/48th

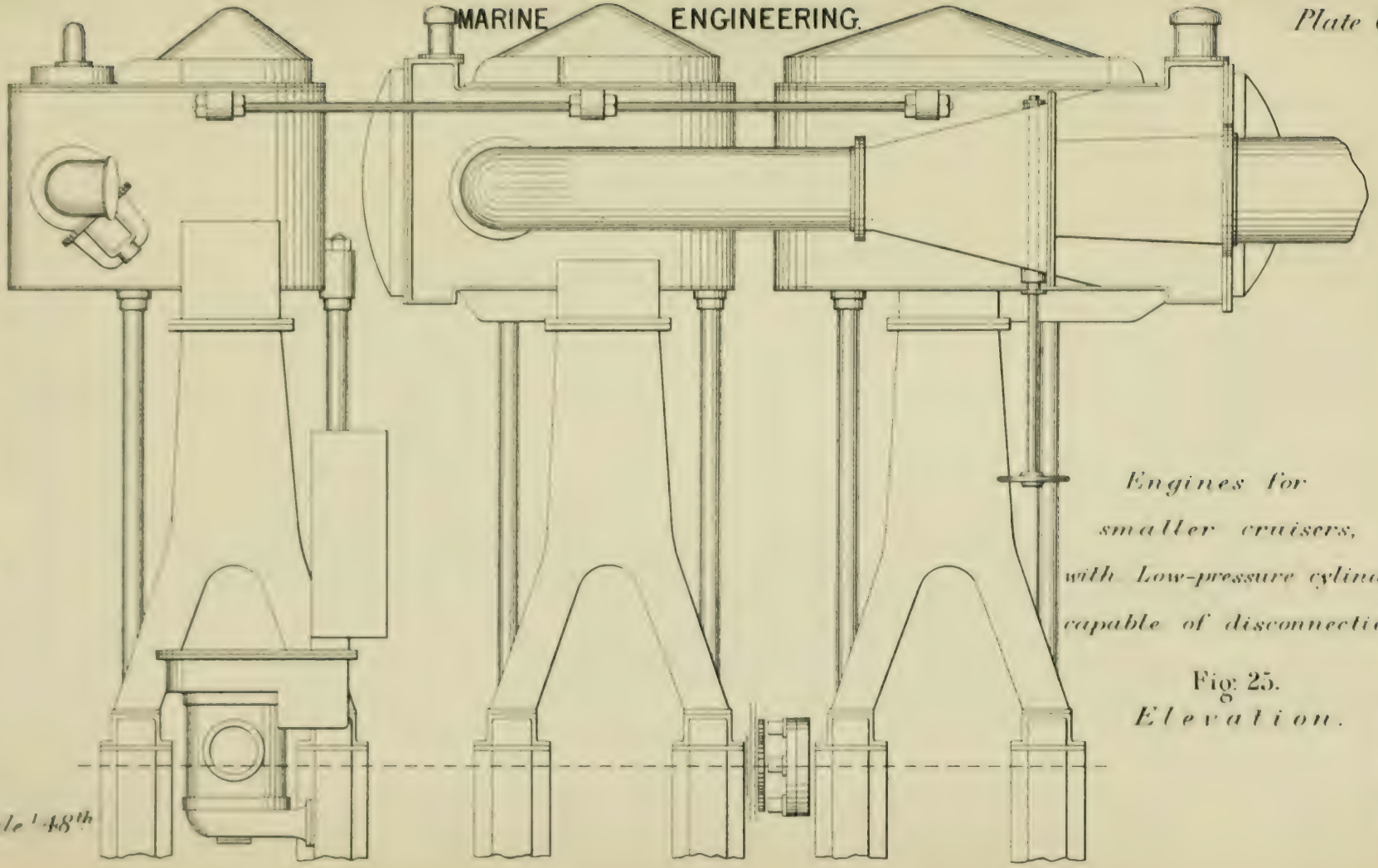
Navy Engines. Fig. 24. *Plan.*



Mechanical Engineers 1891. *Scale 1-48th*

Inches 12 0 5 10 15 20 Feet 25

Plate 67.



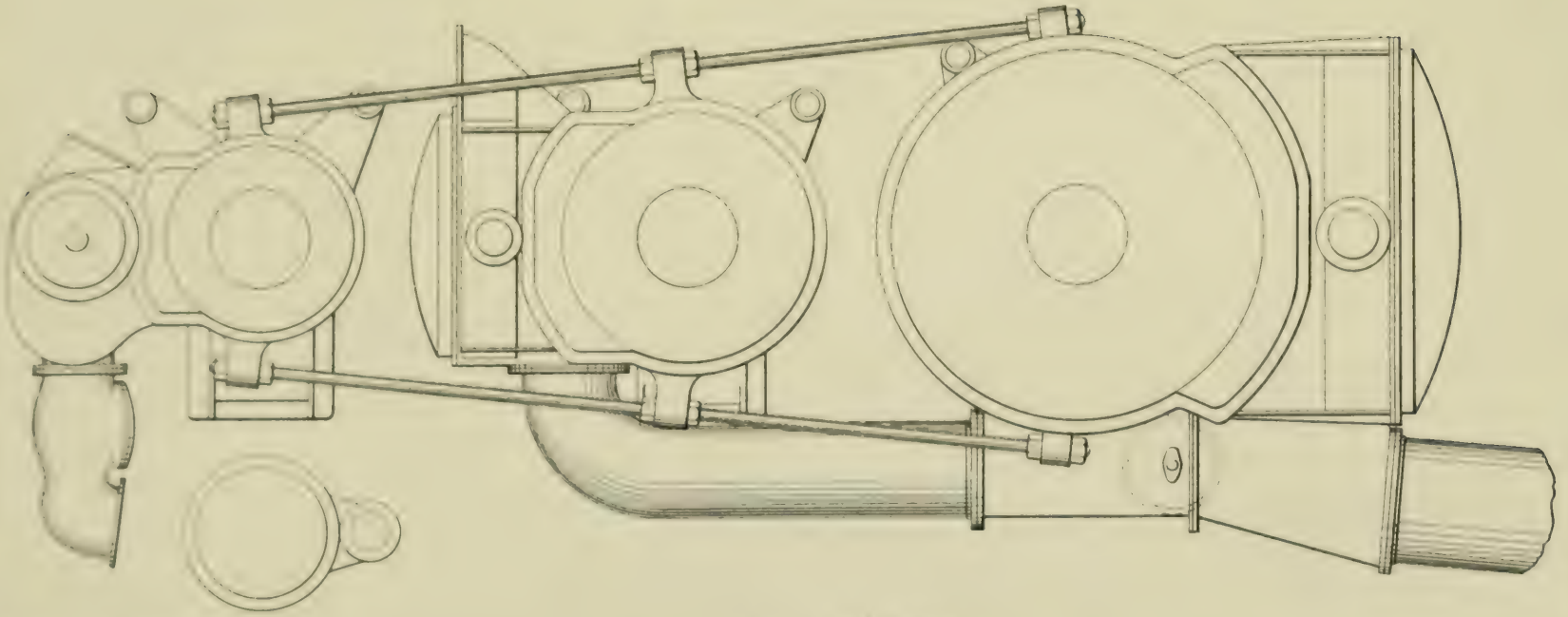
Engines for smaller cruisers, with Low-pressure cylinder capable of disconnection.

Fig. 25.
Elevation.

Scale 1-48th

Engines for smaller cruisers, with Low-pressure cylinder capable of disconnection.

Fig. 26. *Plan.*



Mechanical Engineers 1891. *Scale 1/48th*

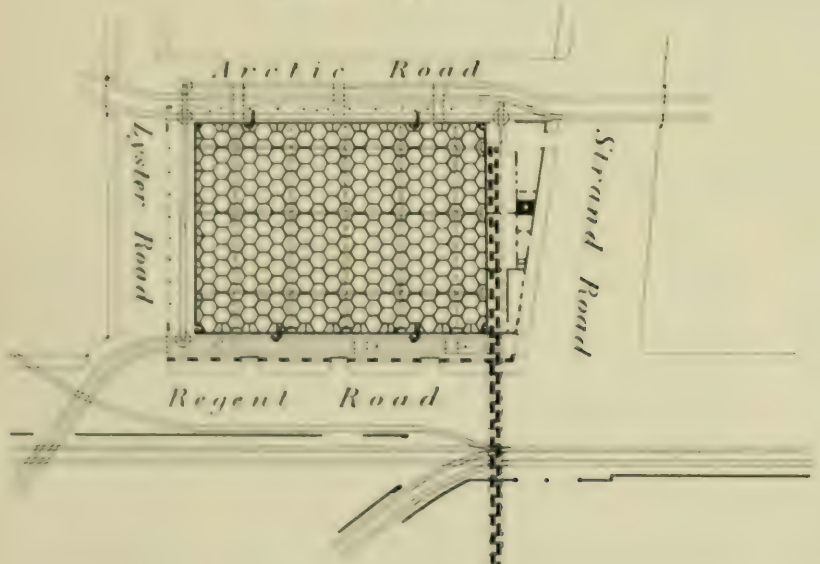
ins 12 0 5 10 15 20 25 Feet

Plate 69.

GRAIN WAREHOUSING MACHINERY.

Fig 1. *Sectional Plan of Bootle Granary.*

Scale 1 2400th



Suck Weighing Machine.

Scale 1 40th

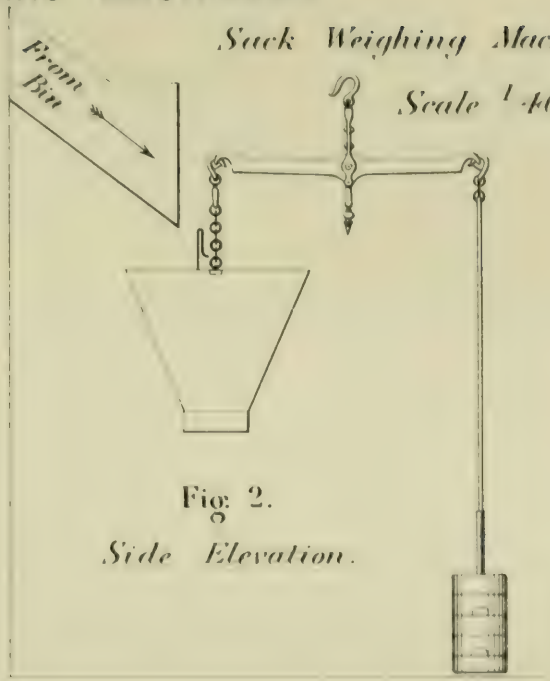


Fig 2.
Side Elevation.

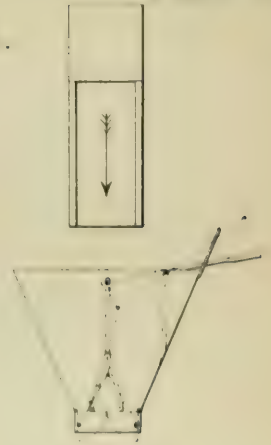


Fig 3.
End Elevation.

Mechanical Engineers 1891. *Scale 1 2400th*

Feet 100 50 0 100 200 300 400 500 600 700 800 900 1000 Feet

0 1/8 mile

GRAIN WAREHOUSING MACHINERY.

Fig. 4. *Longitudinal Section of Granary.*

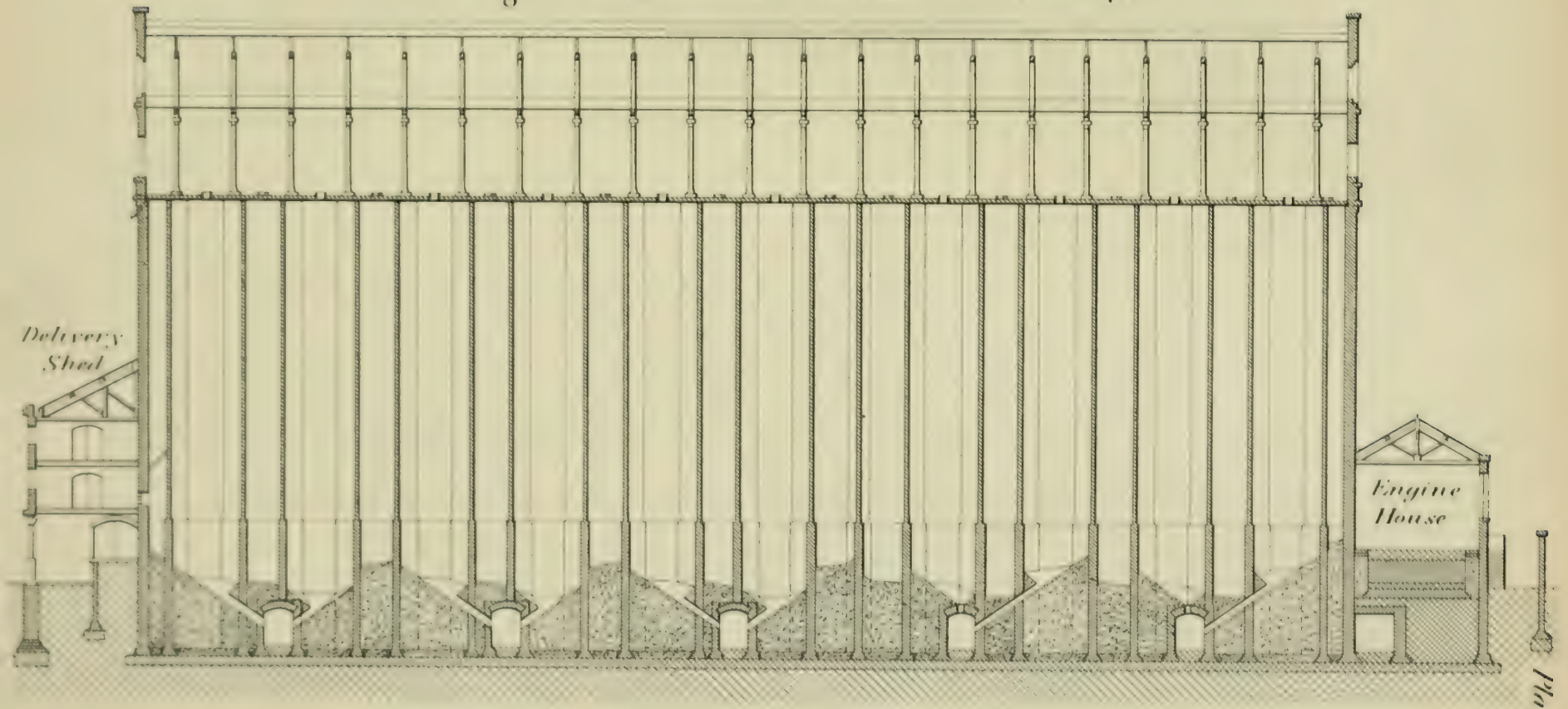


Plate 71.

Fig. 5. *Transverse Section of Granary.*

Scale 1/480th

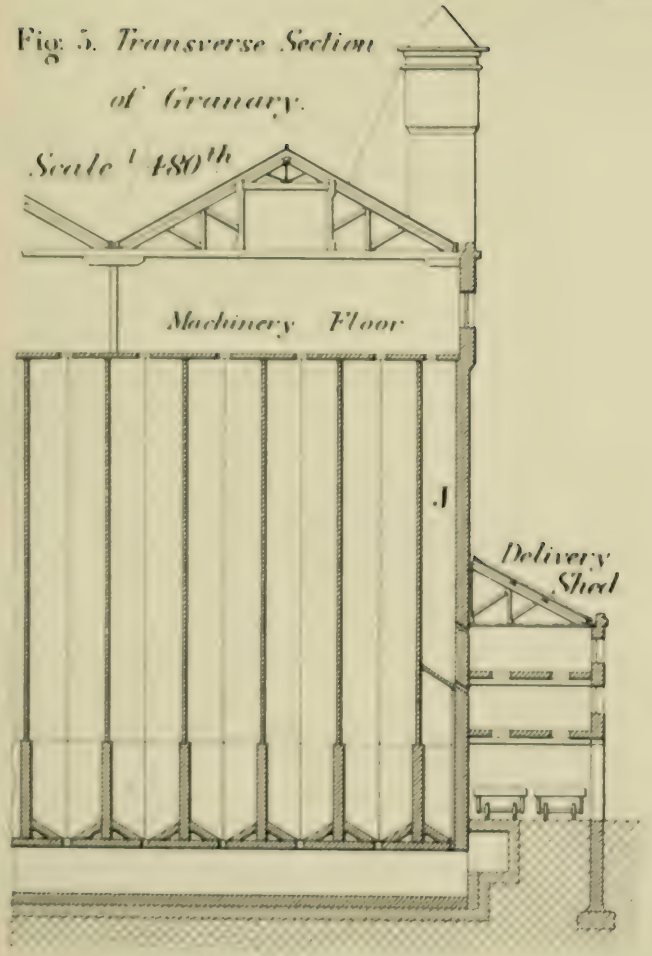
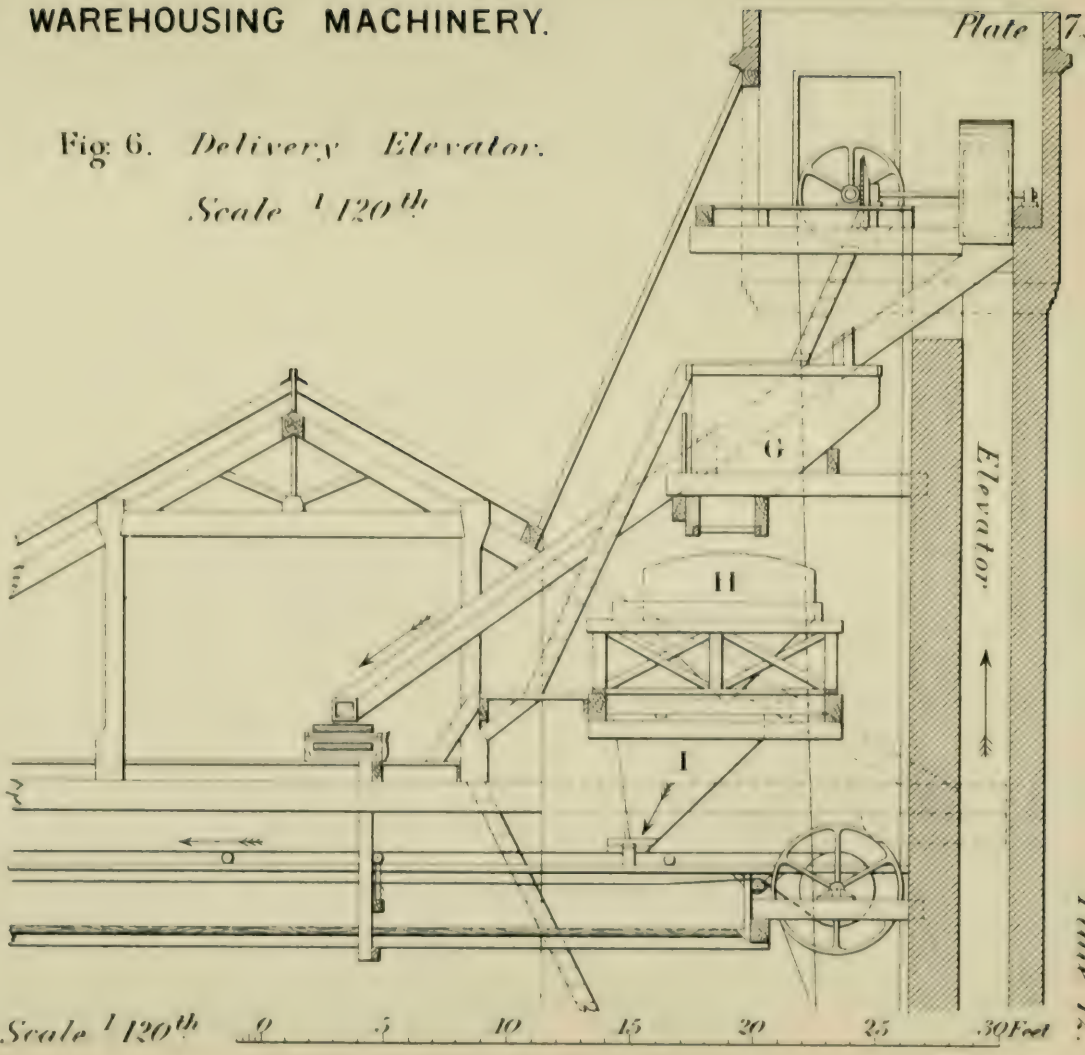


Fig. 6. *Delivery Elevator.*

Scale 1/120th



Scale 1/120th 0 5 10 15 20 25 30 Feet

Mechanical Engineers 1891.

Plate 72.

GRAIN WAREHOUSING MACHINERY.

Receiving Elevator in Granary.

Fig. 7.

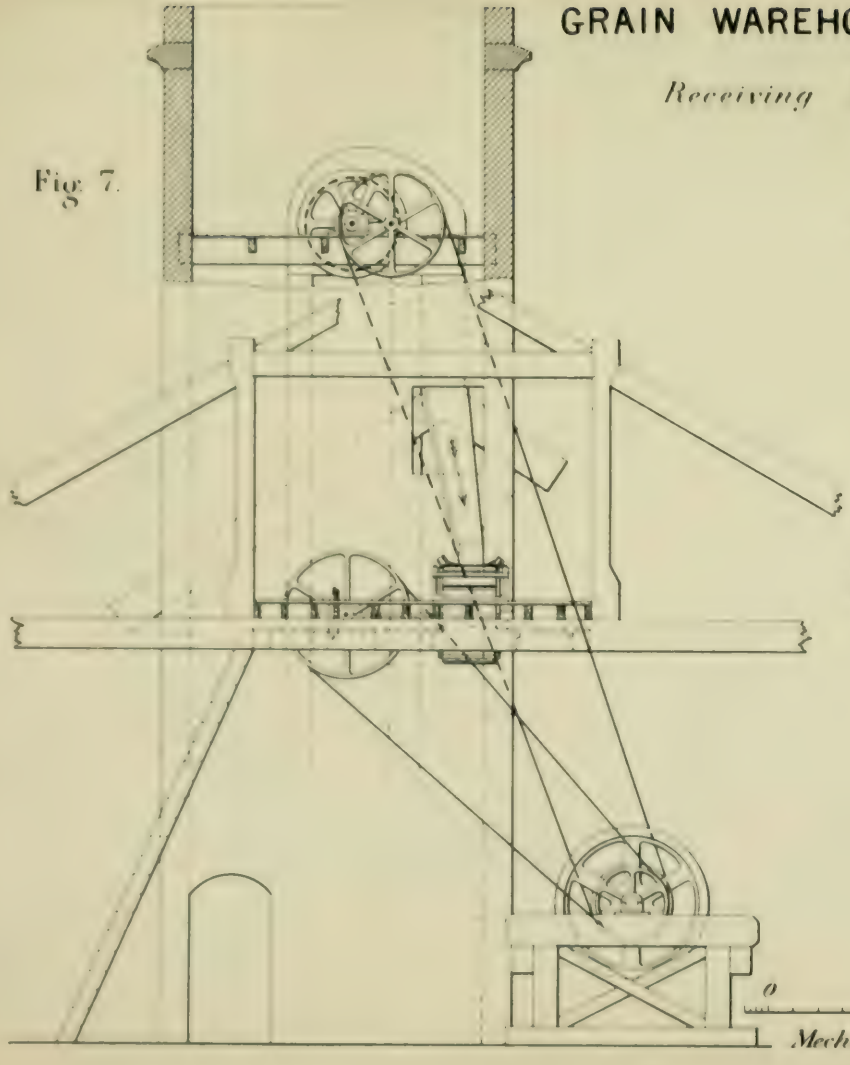
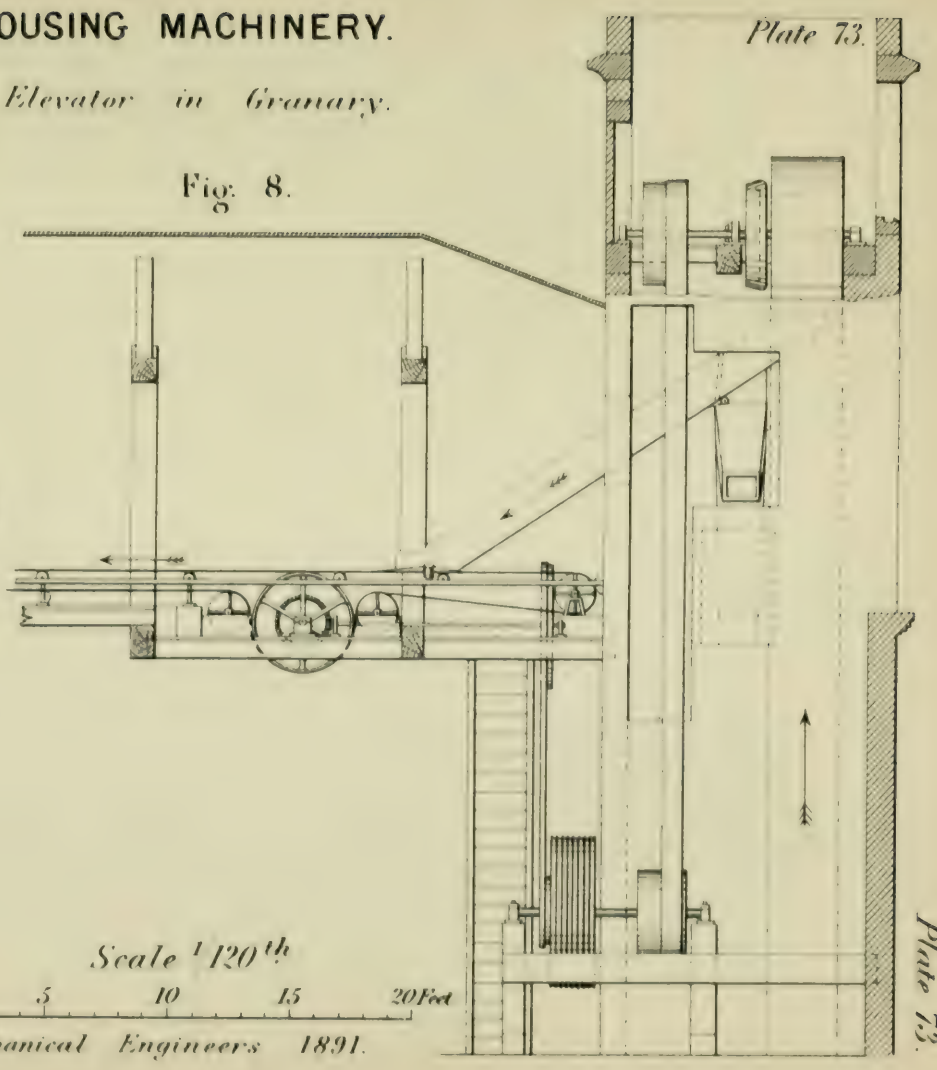


Fig. 8.

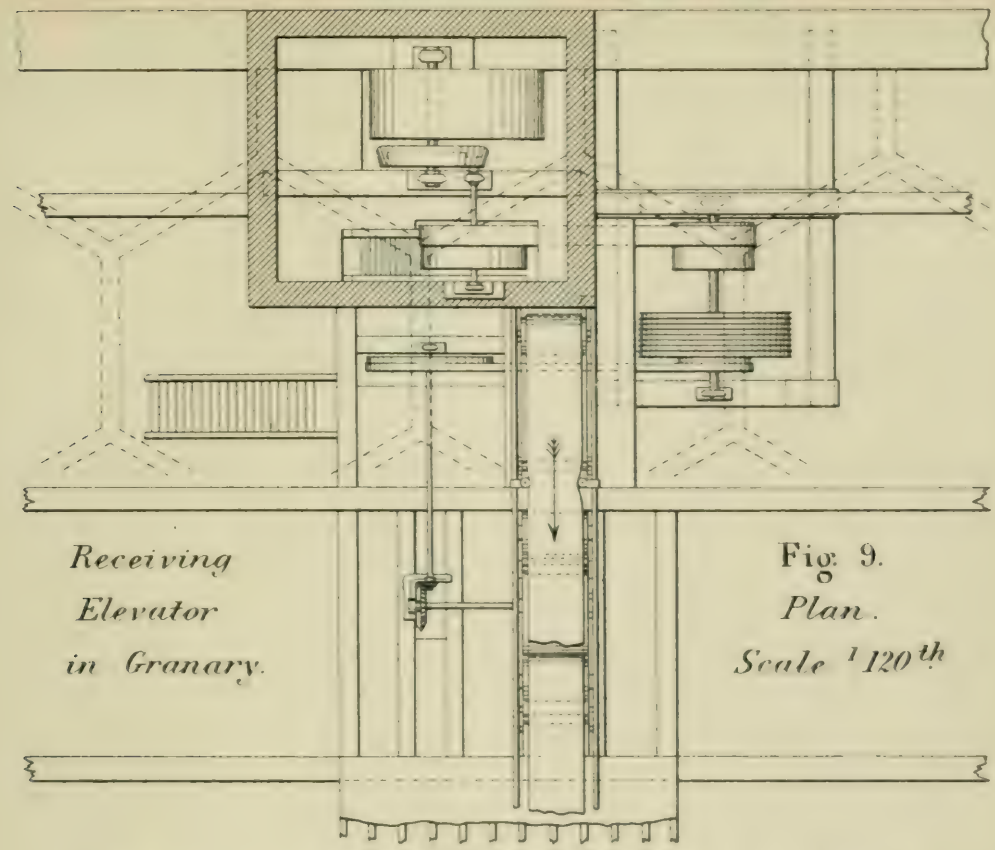


Scale 1/120th

0 5 10 15 20 Feet

Mechanical Engineers 1891.

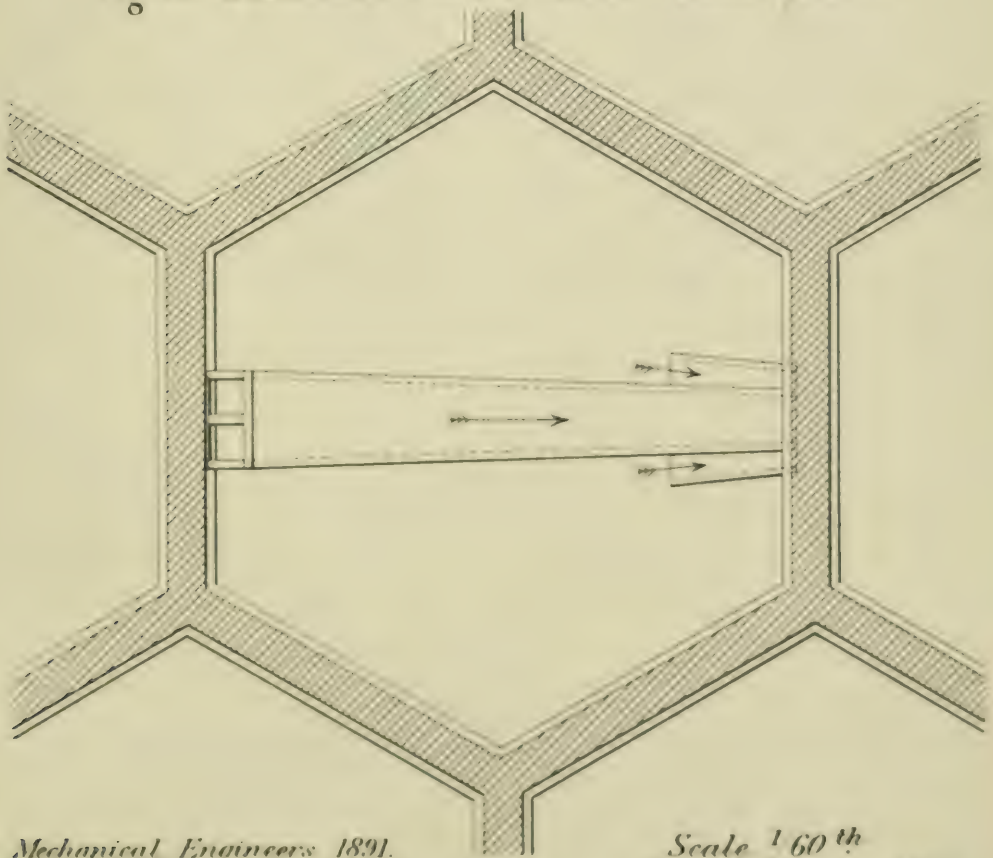
Plate 73.



Receiving Elevator in Granary.

Fig. 9. *Plan. Scale 1/120th*

Fig. 10. *Sectional Plan of Bin. Scale 1/60th*



Mechanical Engineers 1891.

Scale 1/60th

Inches 12 0 5 10 15 Feet

Grain Mixer.

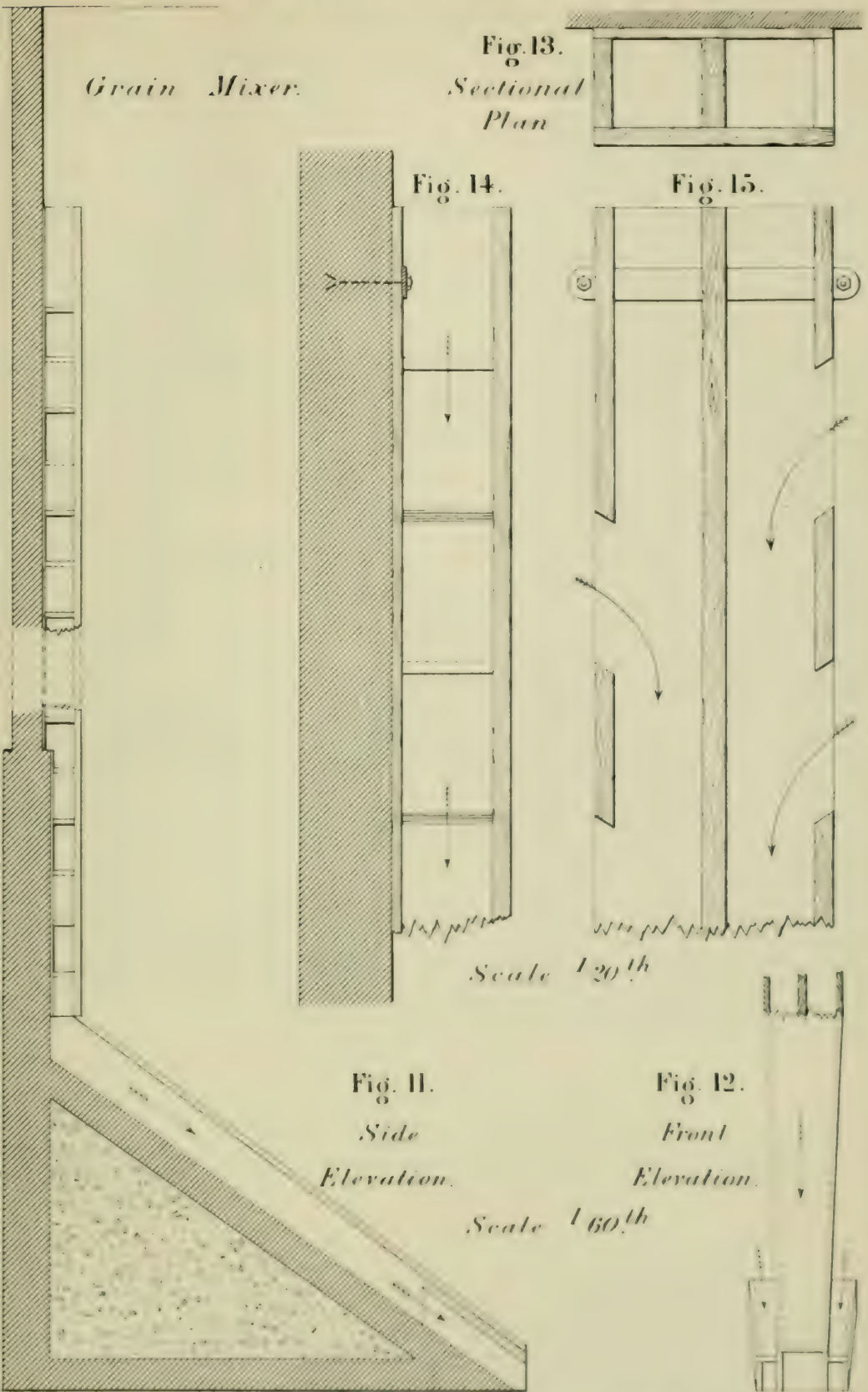


Fig. 13. *Sectional Plan*

Fig. 14.

Fig. 15.

Scale $\frac{1}{20}^{th}$

Fig. 11. *Side Elevation.*

Fig. 12. *Front Elevation.*

Scale $\frac{1}{60}^{th}$

Mechanical Engineer 1891

Scale $\frac{1}{20}^{th}$

Inches 12 6 0 1 2 3 4 5 *Feet*

Subway under Quays and Roadway.

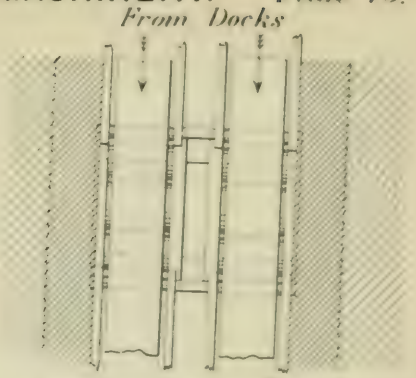


Fig: 16. *Sectional Plan.*

Scale 1/120th

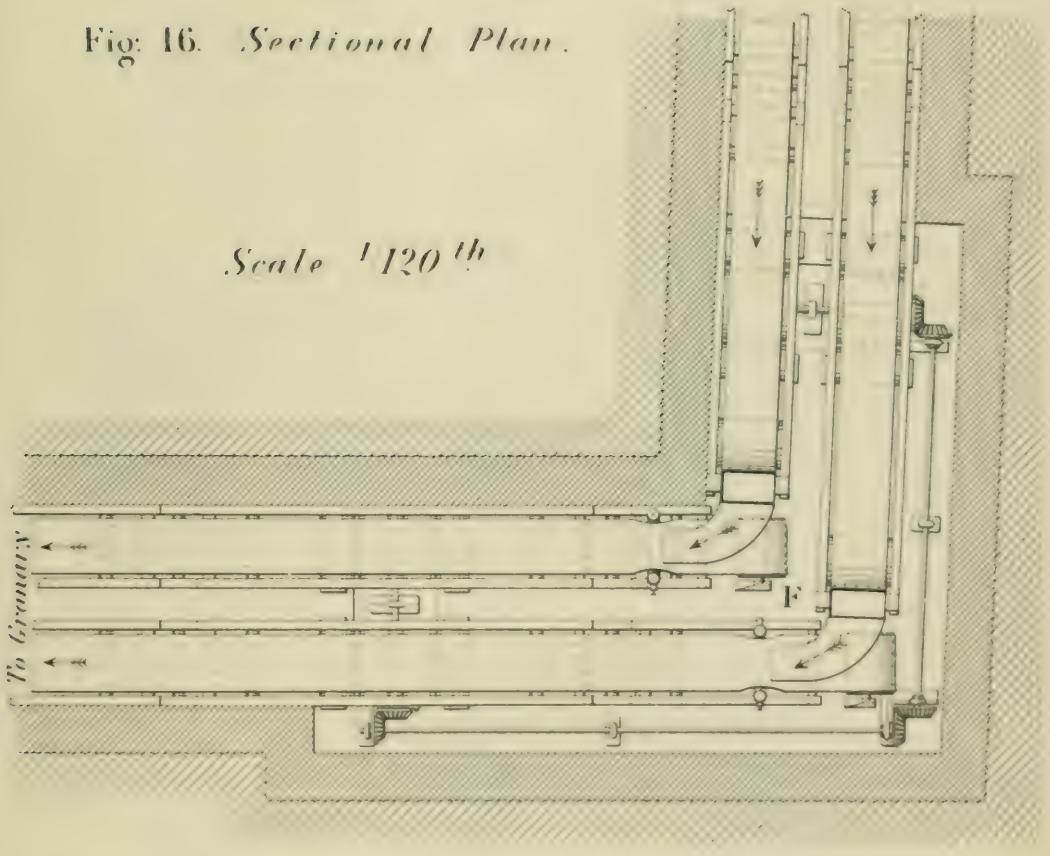
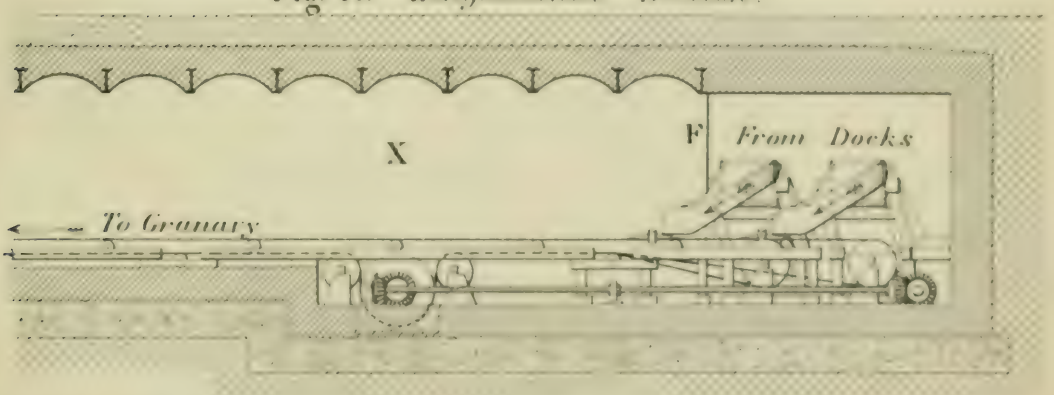


Fig: 17. *Longitudinal Section.*



Mechanical Engineers 1891. *Scale 1/120th*

0 5 10 15 20 25 30 35 40

GRAIN WAREHOUSING MACHINERY.

Subway under Quays and Roadway.

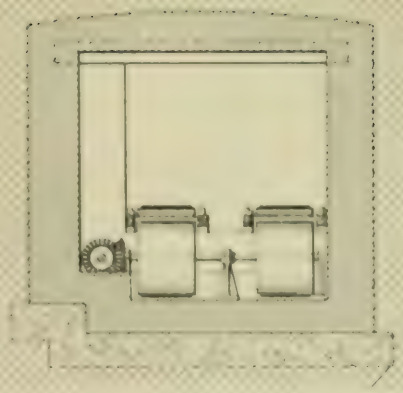


Fig: 18.
Transverse Section at X, Plate 76.

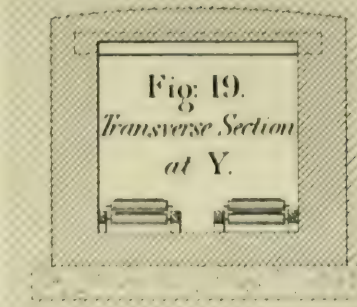


Fig: 19.
Transverse Section at Y.

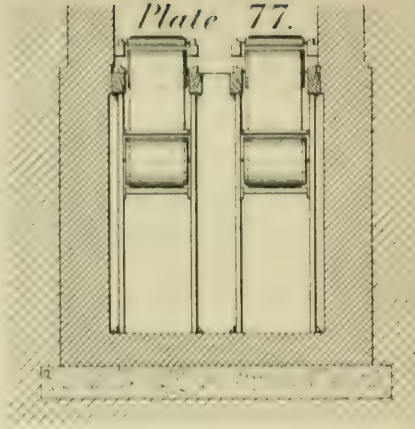


Fig: 20.
Transverse Section at Z.

Plate 77.

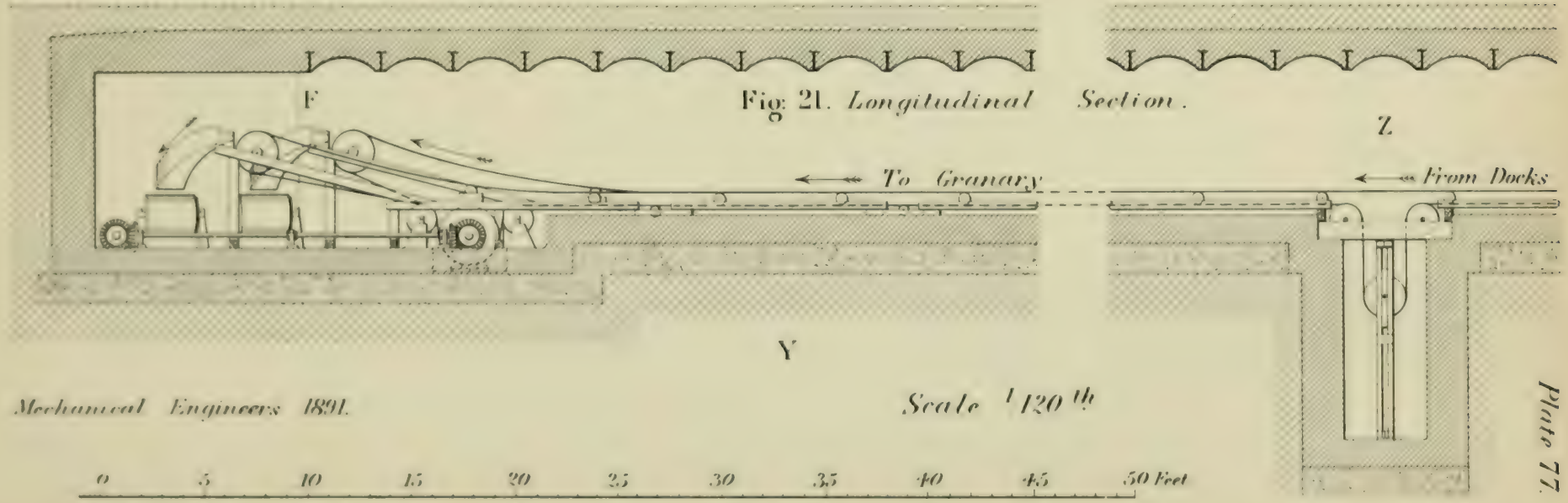


Fig: 21. *Longitudinal Section.*

Mechanical Engineers 1891.

Scale 1/120th

0 5 10 15 20 25 30 35 40 45 50 Feet

Plate 77.

GRAIN WAREHOUSING MACHINERY.

Plate 78.

Dockside Elevator.

Fig. 22. *End Elevation.*

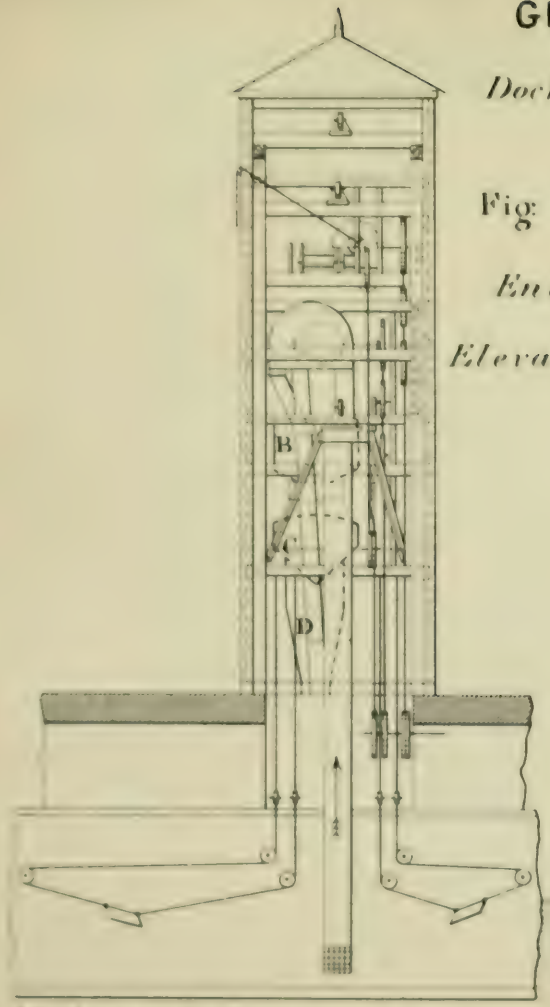
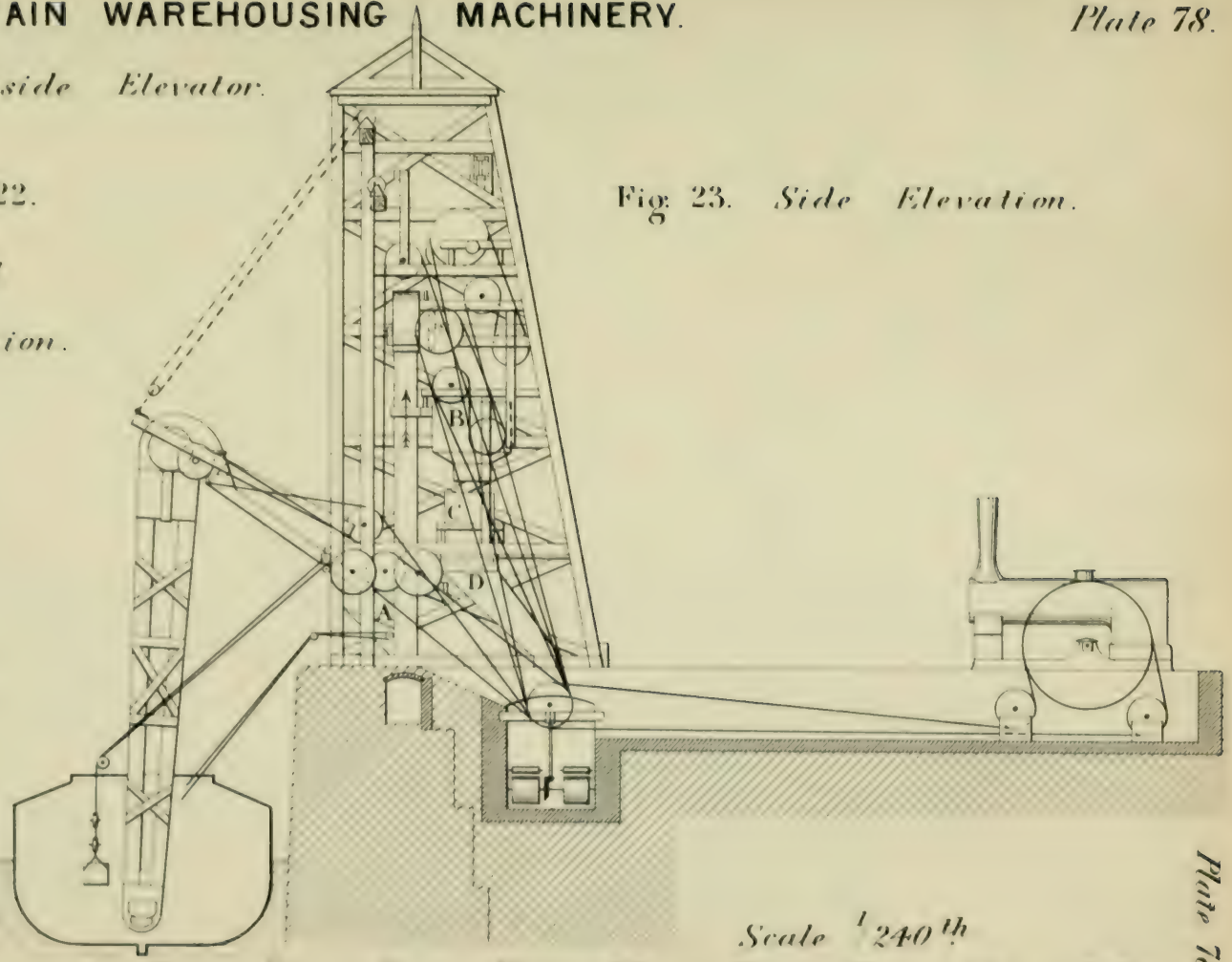


Fig. 23. *Side Elevation.*



Scale $\frac{1}{240}$th

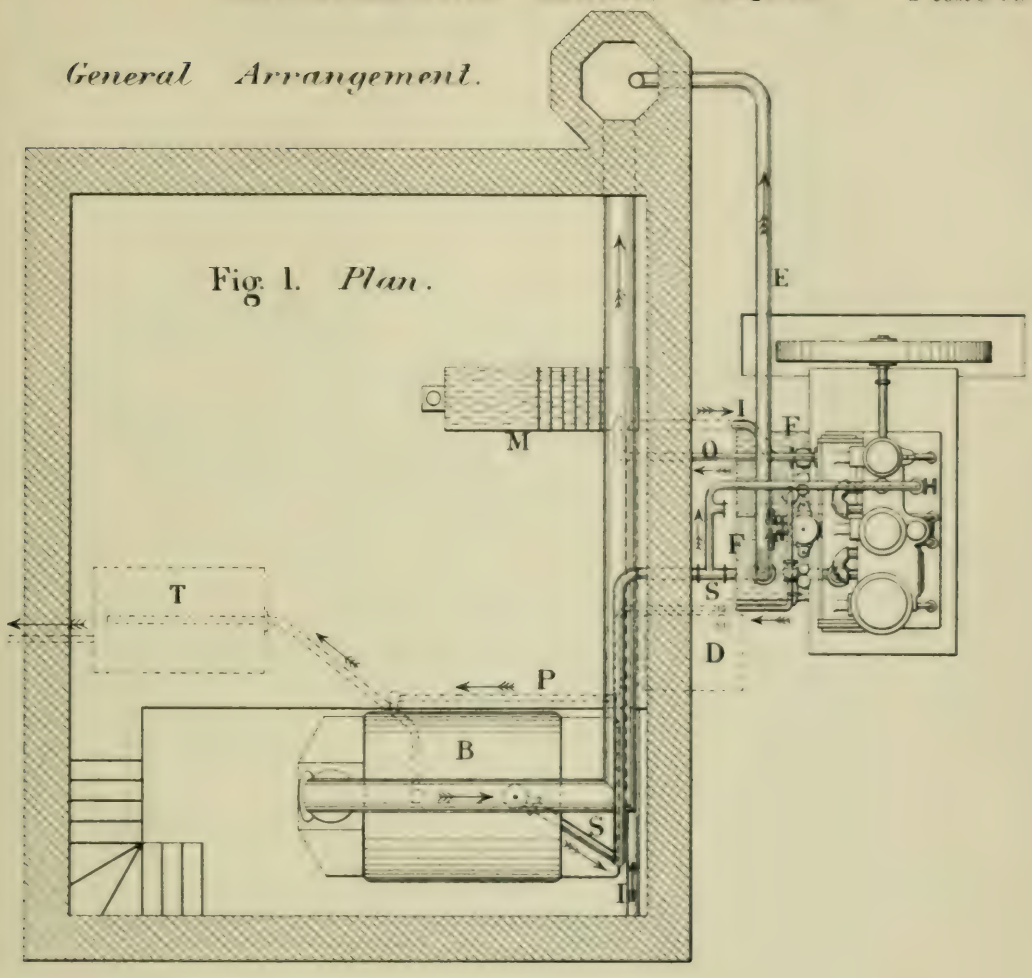
0 10 20 30 40 50 60 70 80 Feet.

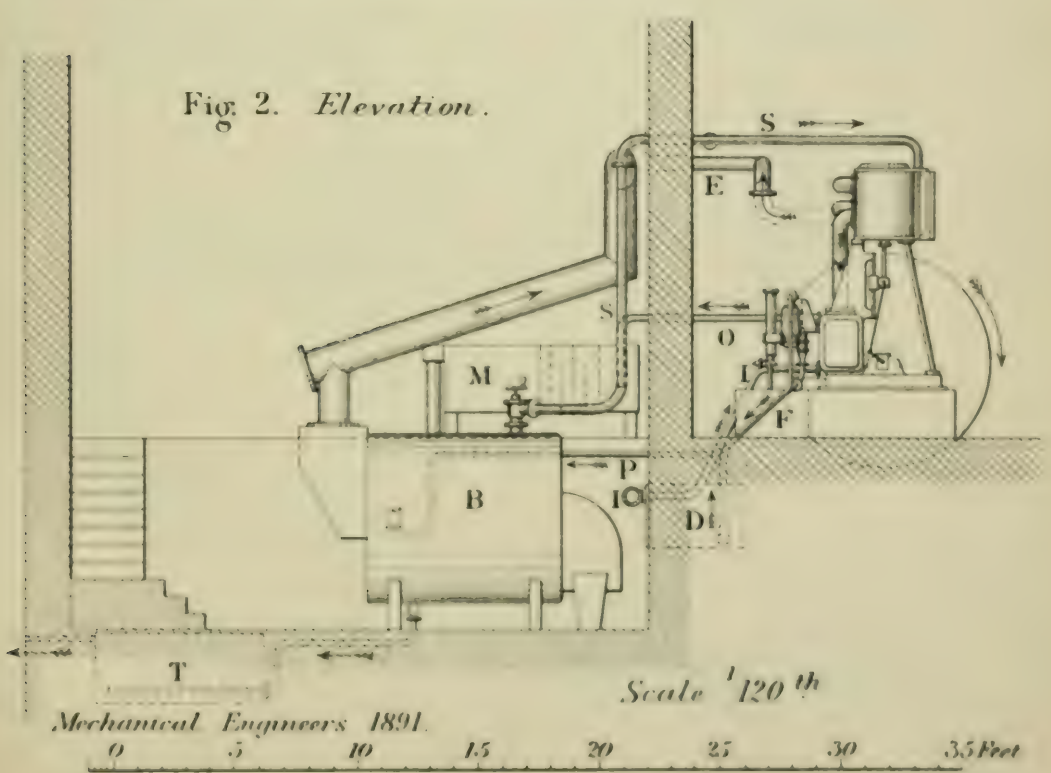
Mechanical Engineers 1891.

Plate 78.

EXPERIMENTAL MARINE ENGINE. *Plate 79.*

General Arrangement.





EXPERIMENTAL MARINE ENGINE.

Fig. 3.

End Elevation.

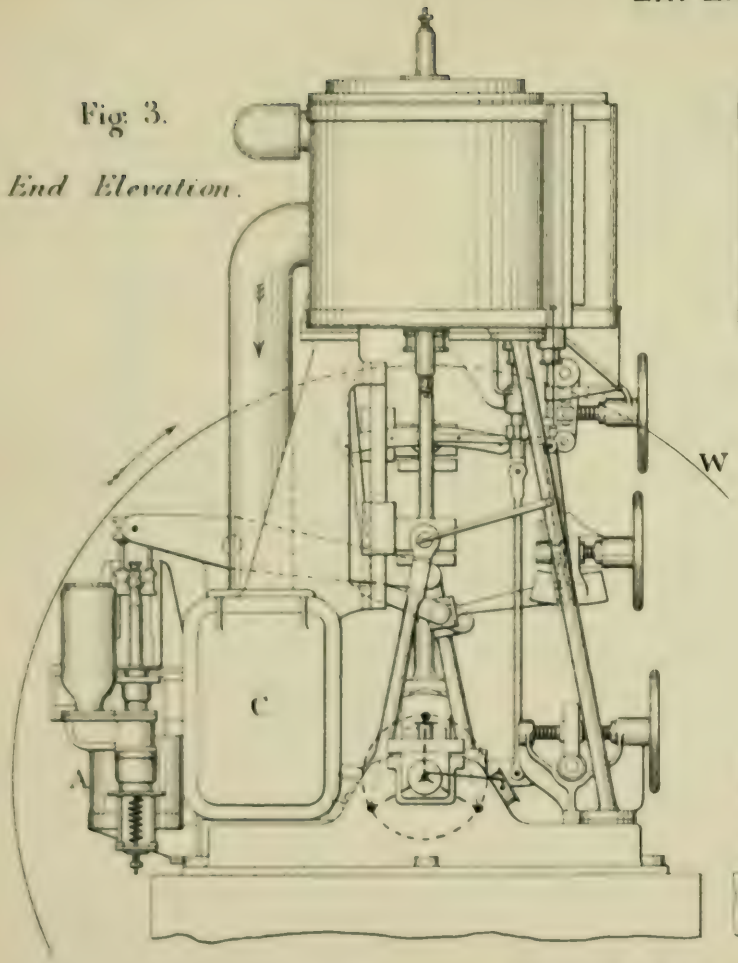
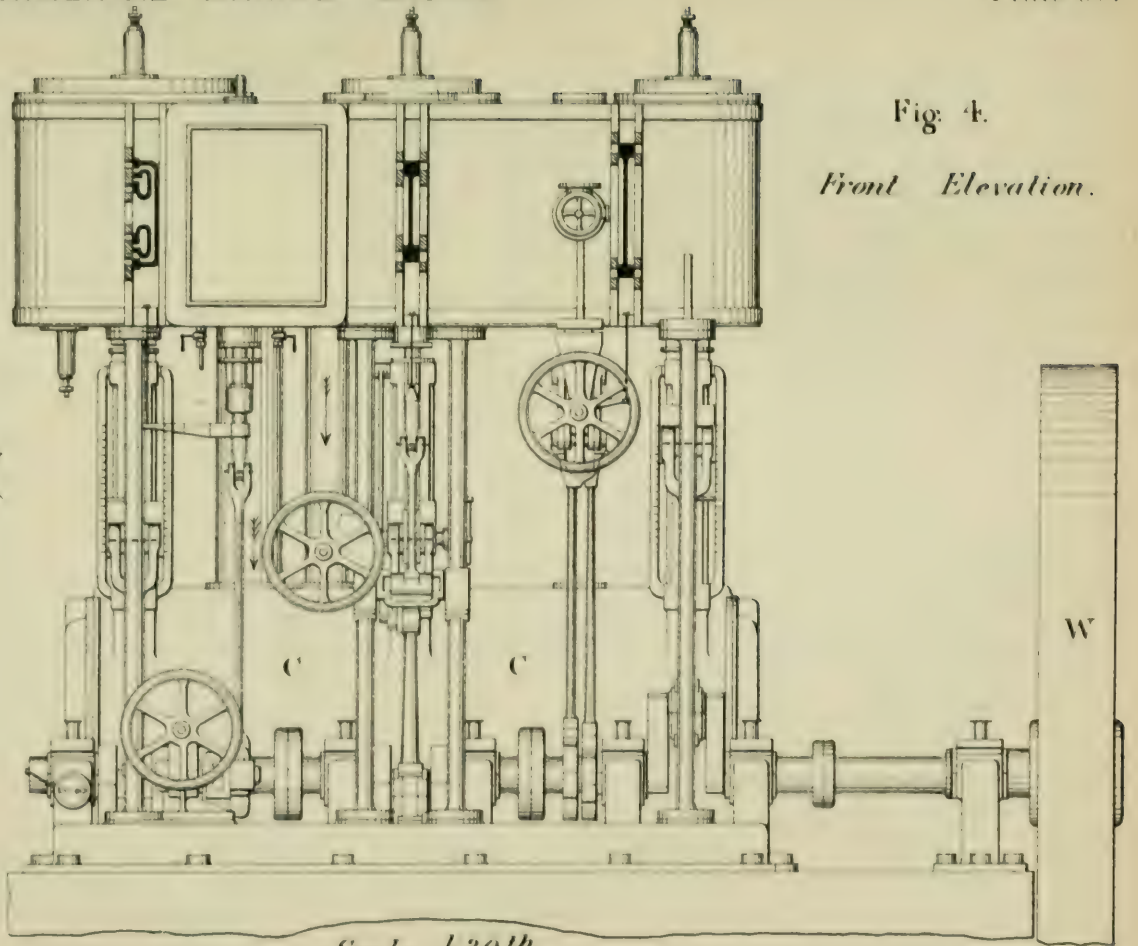


Fig. 4.

Front Elevation.



Scale $\frac{1}{30}$th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 *Feet*

Mechanical Engineers 1891.

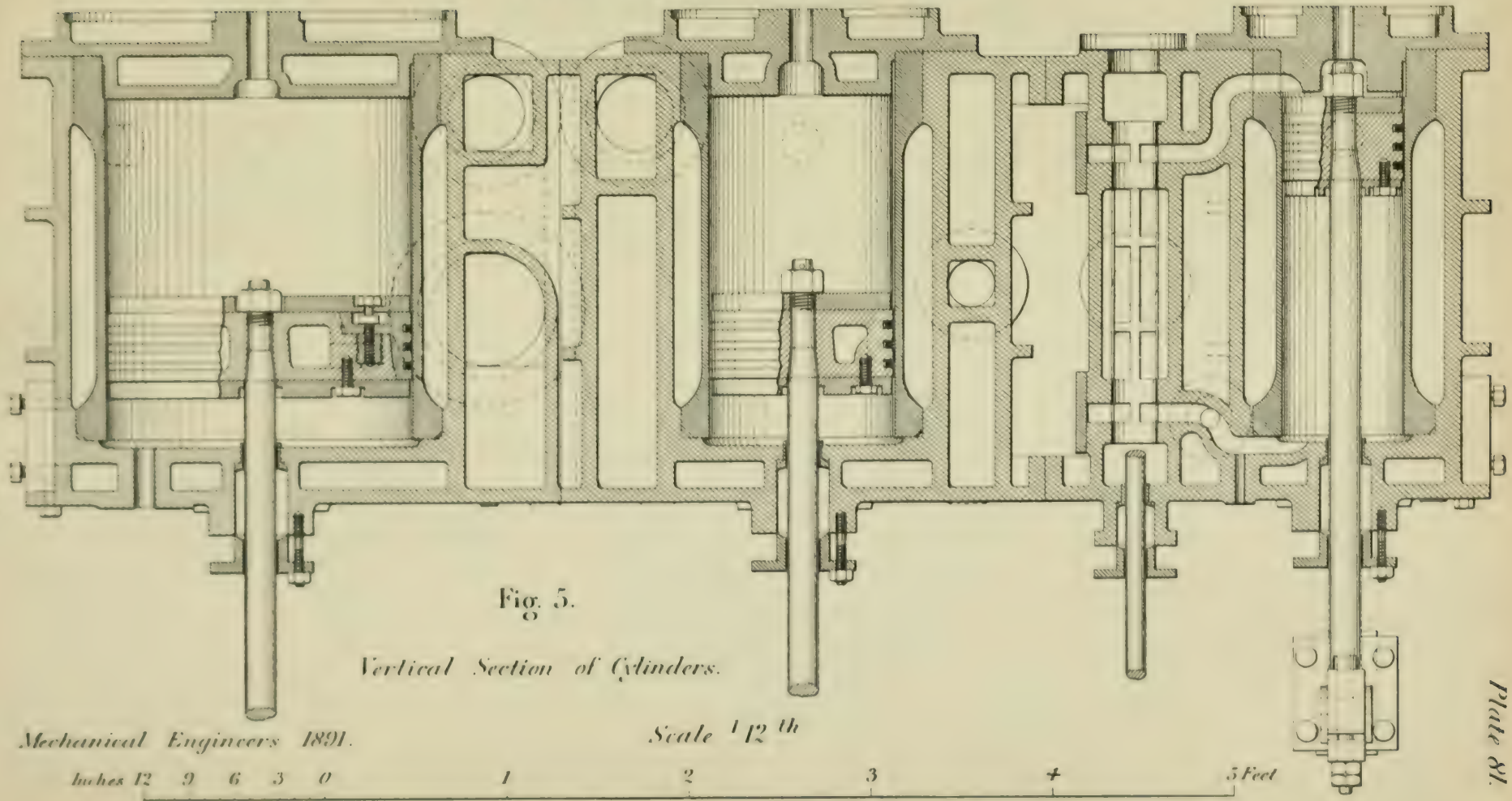


Fig. 5.

Vertical Section of Cylinders.

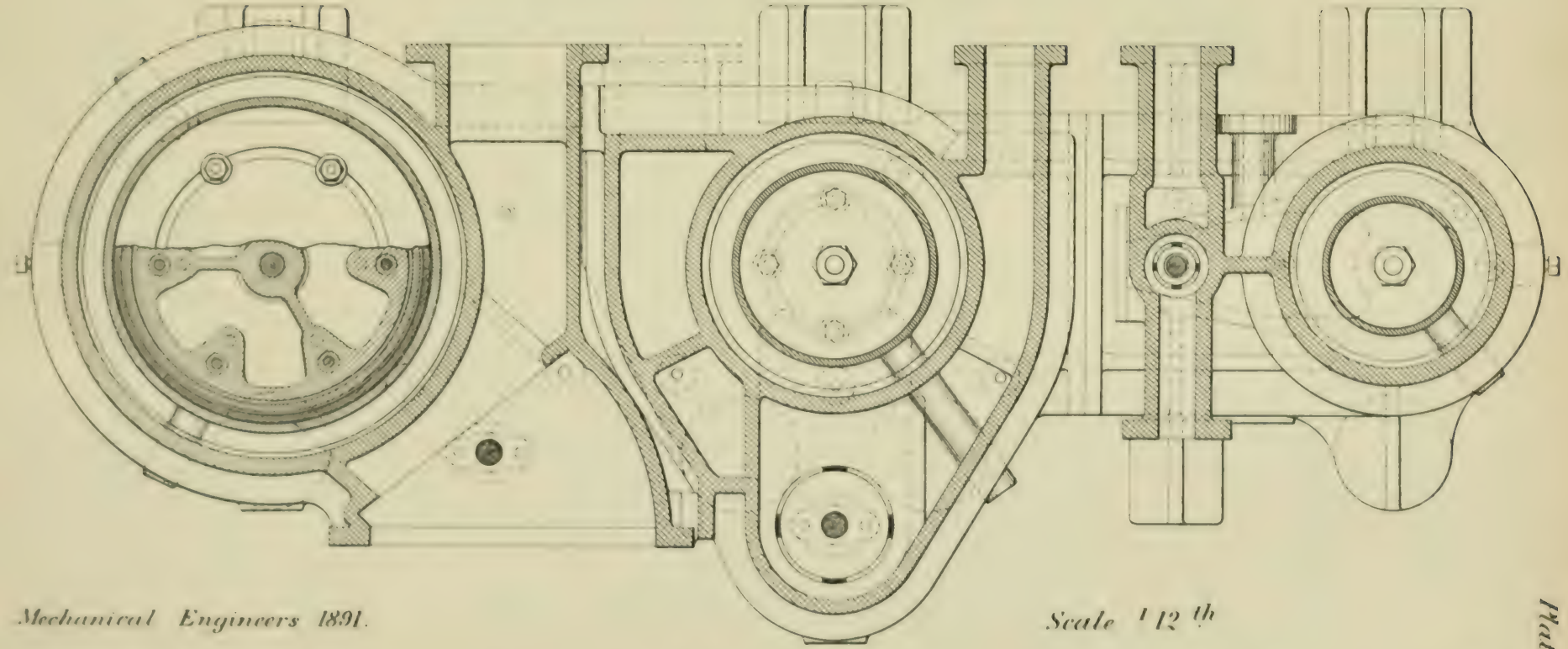
Mechanical Engineers 1891. *Scale 1/12 th*

Inches 12 9 6 3 0 1 2 3 4 5 *Feet*

Plate 81.

EXPERIMENTAL MARINE ENGINE.

Fig. 6. *Sectional Plan of Cylinders.*



Mechanical Engineers 1891.

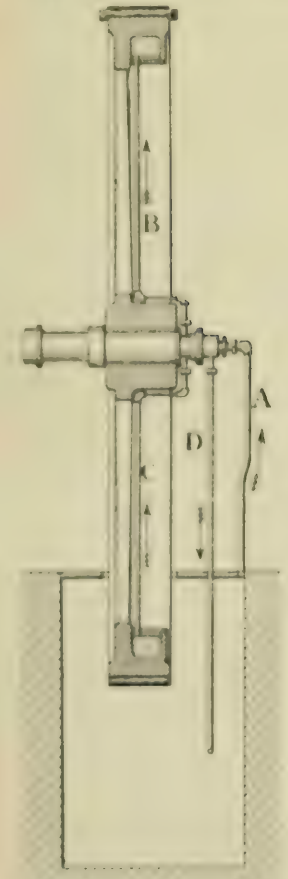
Scale 1/12 th

Inches 12 9 6 3 0 1 2 3 4 5 6 Feet

Plate 82.

EXPERIMENTAL MARINE ENGINE.

Fig 7. *Vertical Section.*



Dynamometer Brake.

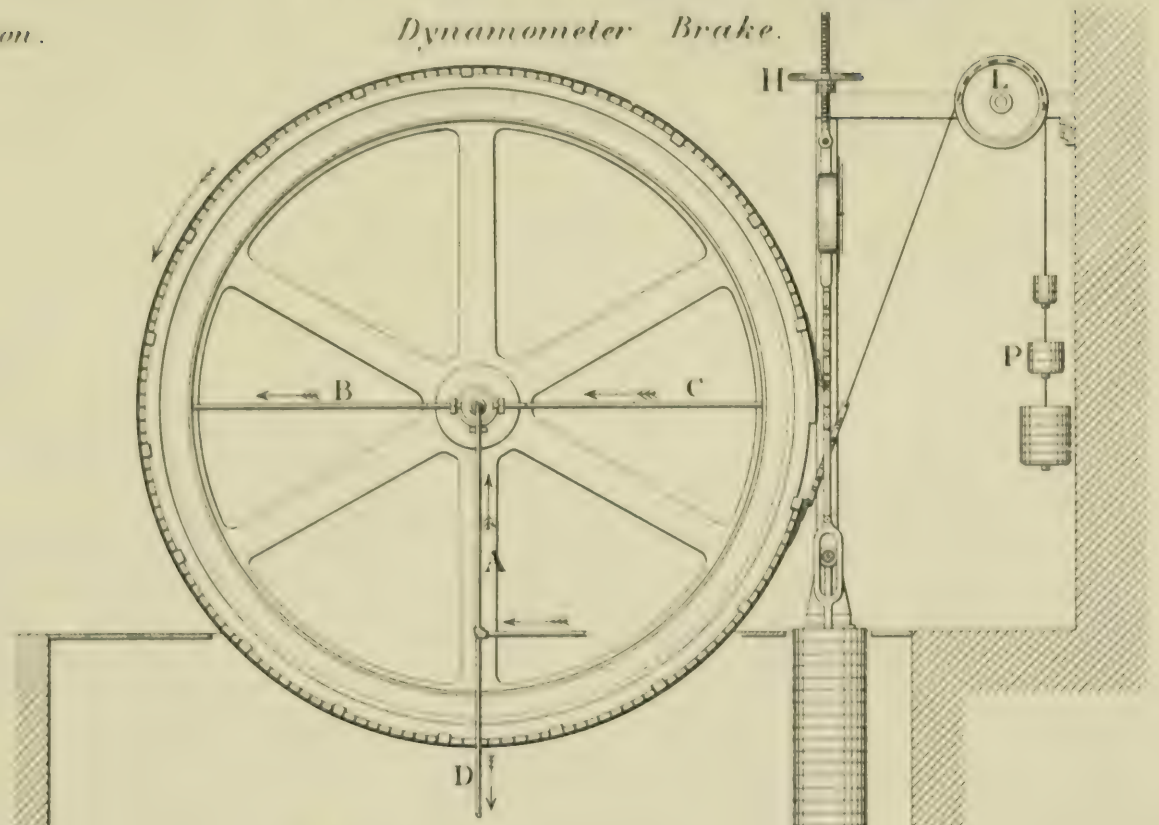
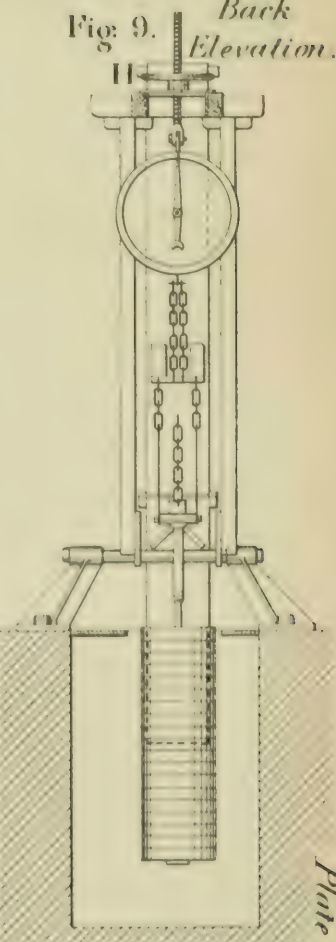


Fig 8. *End Elevation.*

Fig 9. *Back Elevation.*



Scale 1/40th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

Mechanical Engineers 1891.

EXPERIMENTAL MARINE ENGINE.

Dynamometer Brake.

Centre-Box.

Fig. 10.

Longitudinal Section.

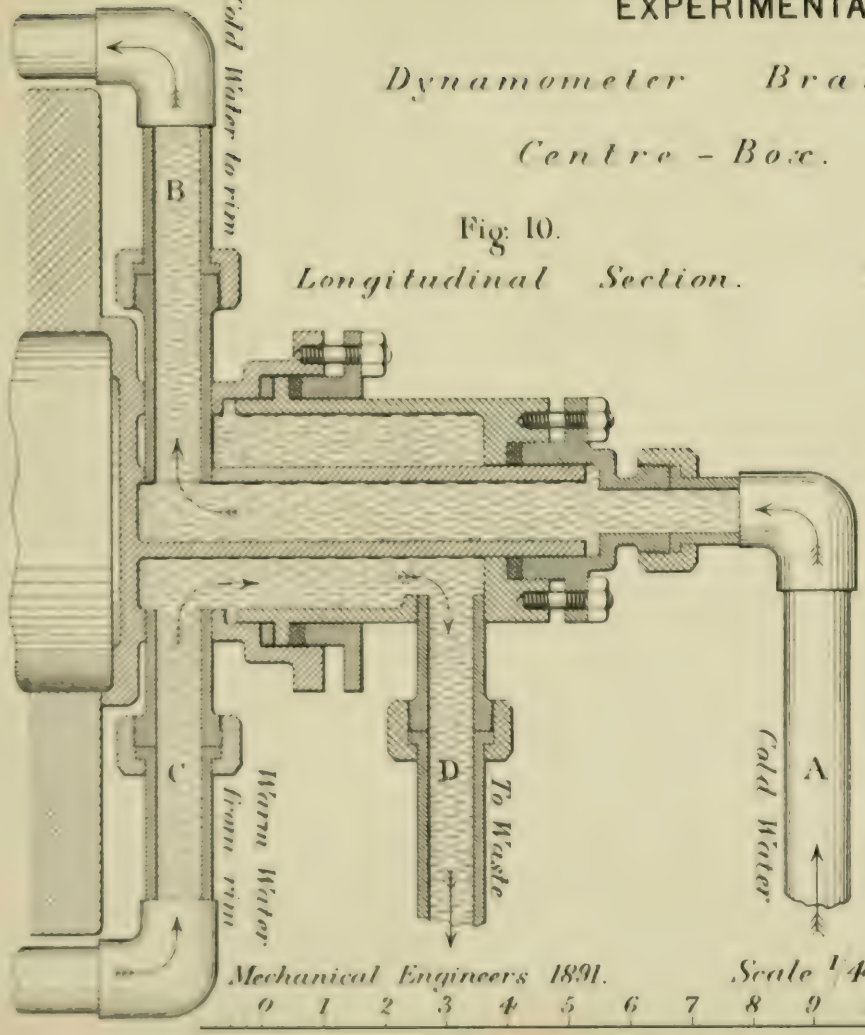


Fig. 11. *End Elevation.*

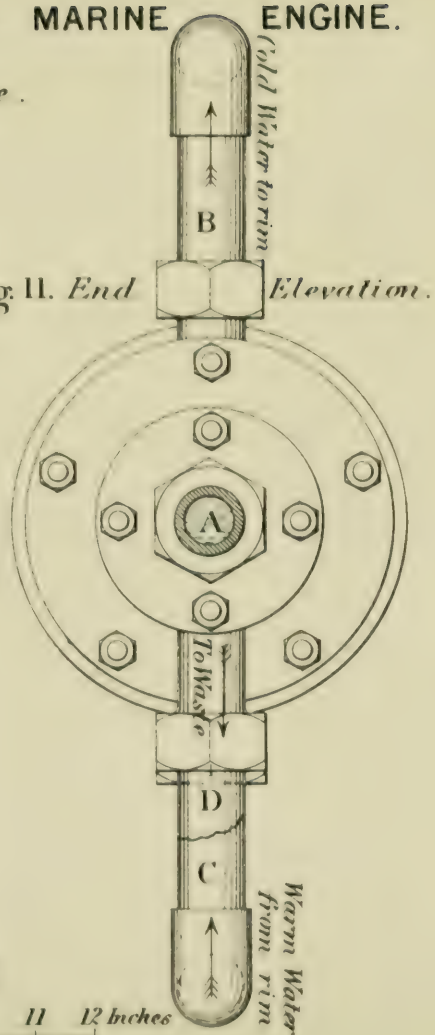


Fig. 12.

Riveted Joints of Boiler.

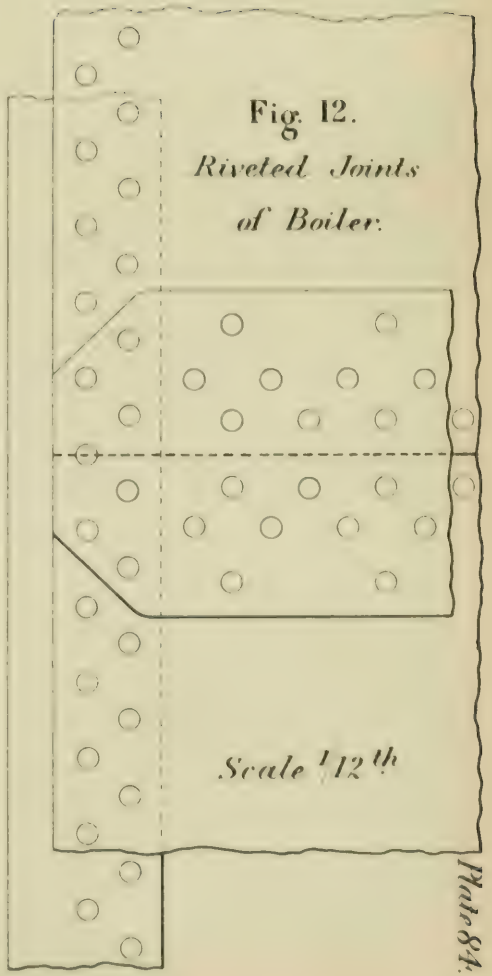
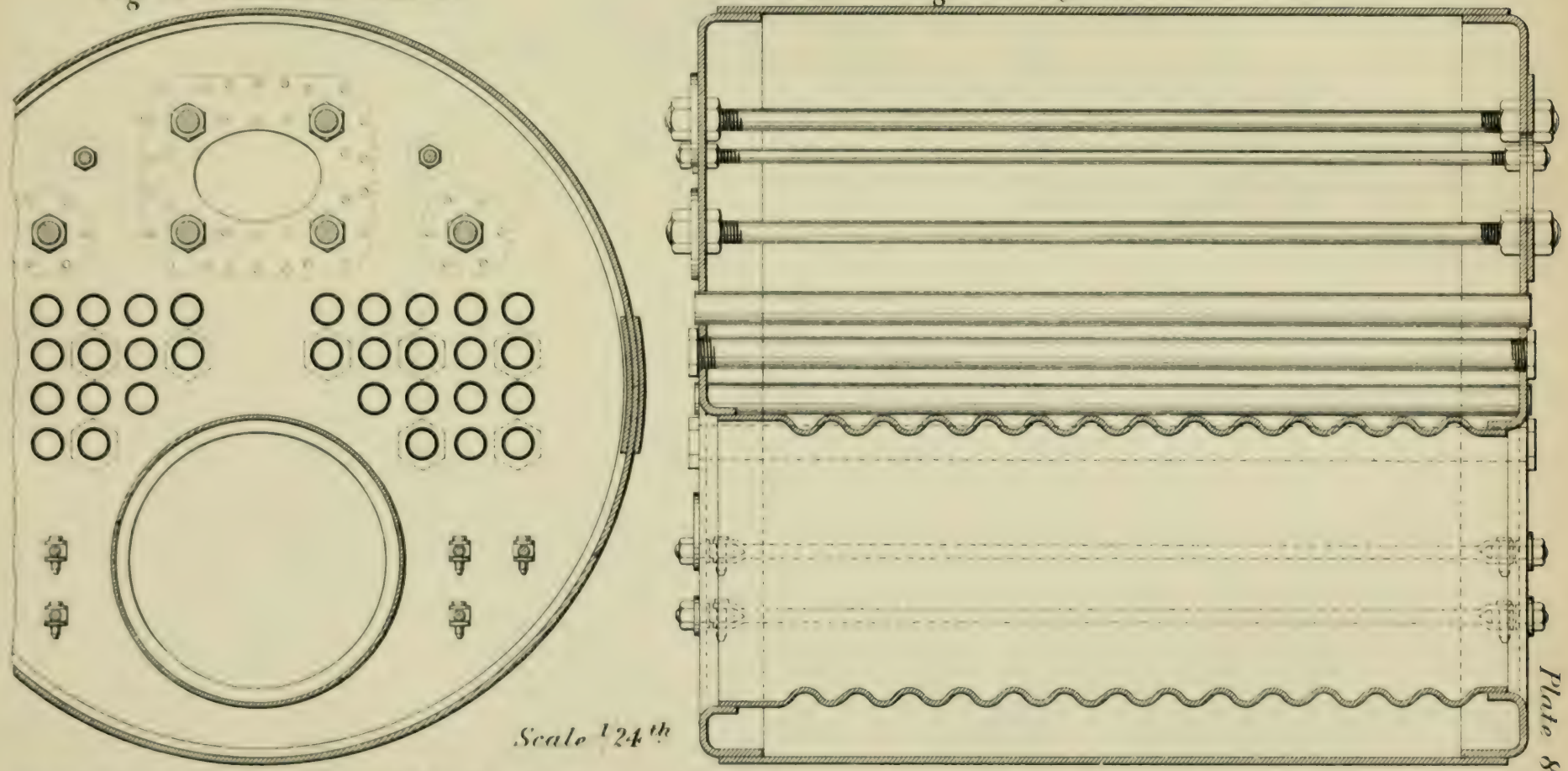


Fig. 13. *Transverse Section.*

Boiler.

Fig. 14. *Longitudinal Section.*



Scale $\frac{1}{24}^{th}$

Mechanical Engineers 1891.

Inches 12 6 0 1 2 3 4 5 6 7 8 *Feet*

Plate 85.

EXPERIMENTAL MARINE ENGINE.

Plate 86.

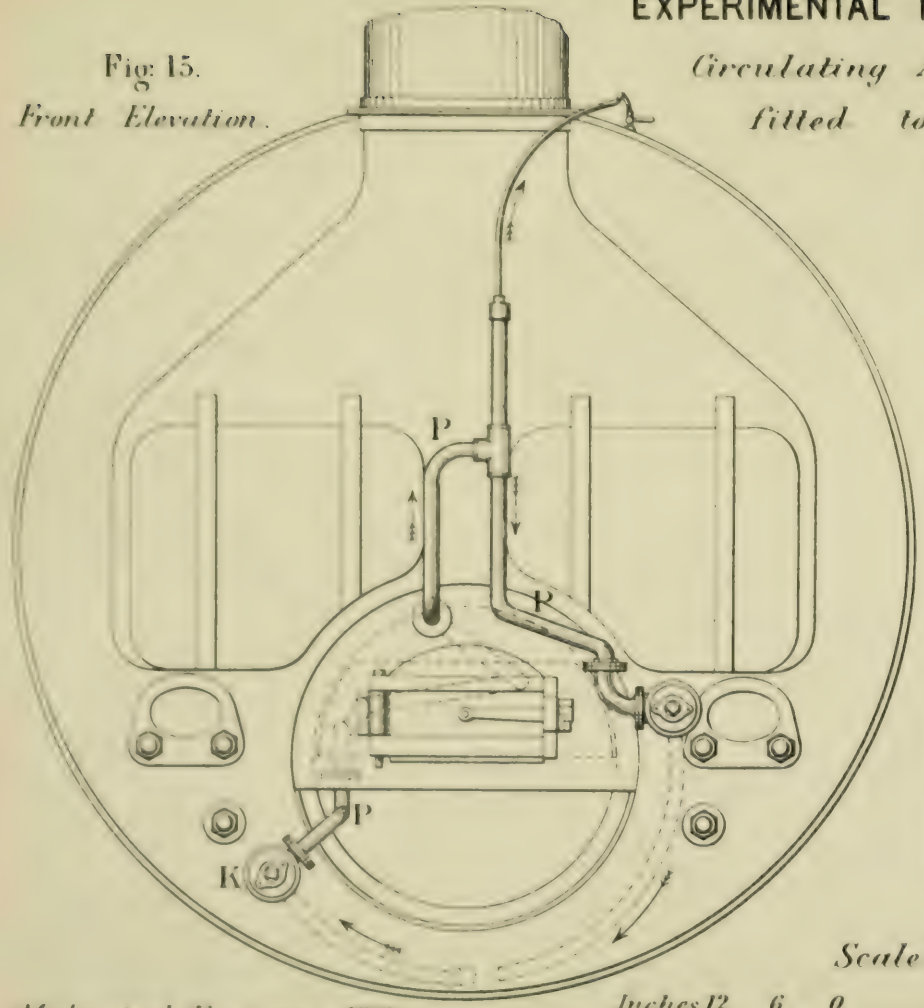
Fig. 15.

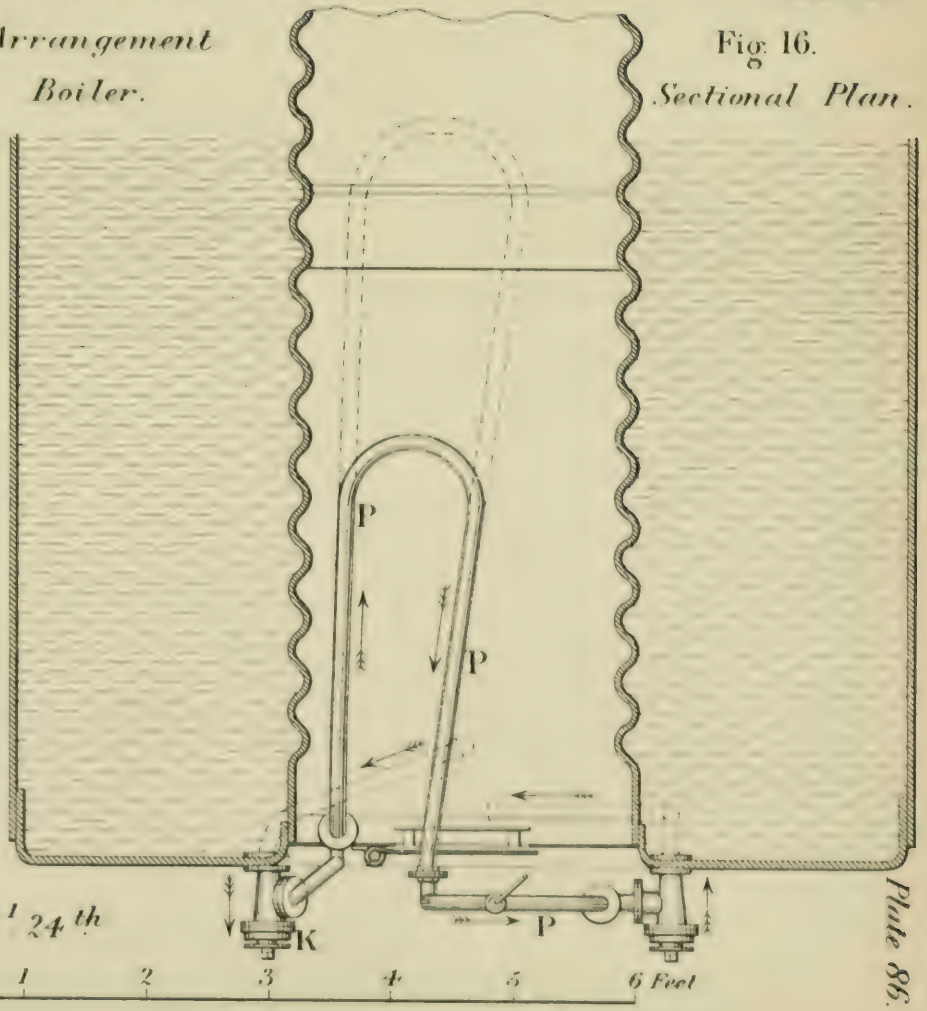
Front Elevation.

Circulating Arrangement fitted to Boiler.

Fig. 16.

Sectional Plan.





Scale $\frac{1}{24}$ th

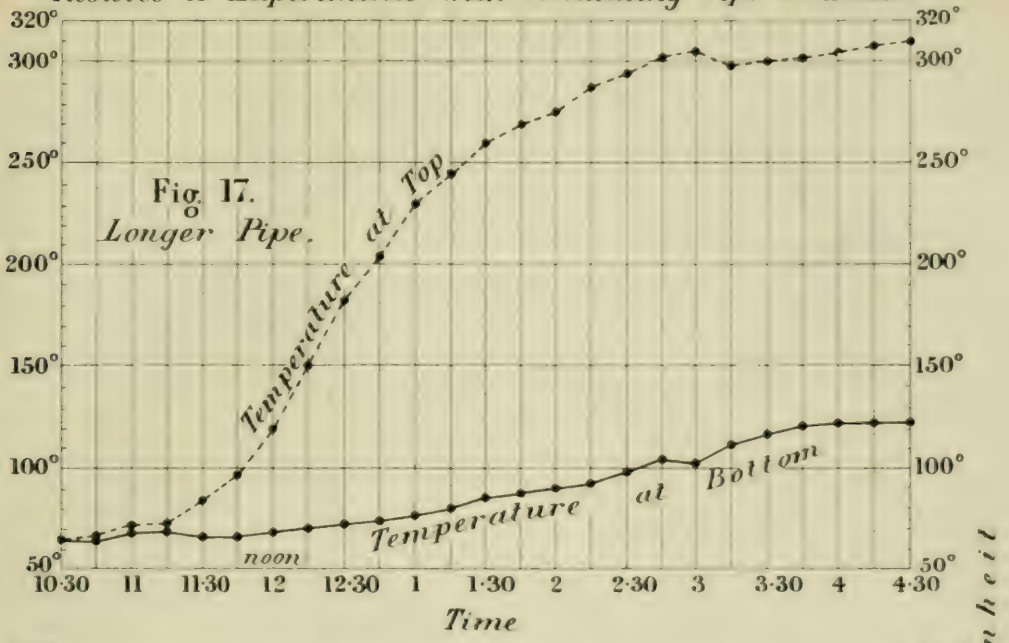
Inches 12 6 0 1 2 3 4 5 6 *Feet*

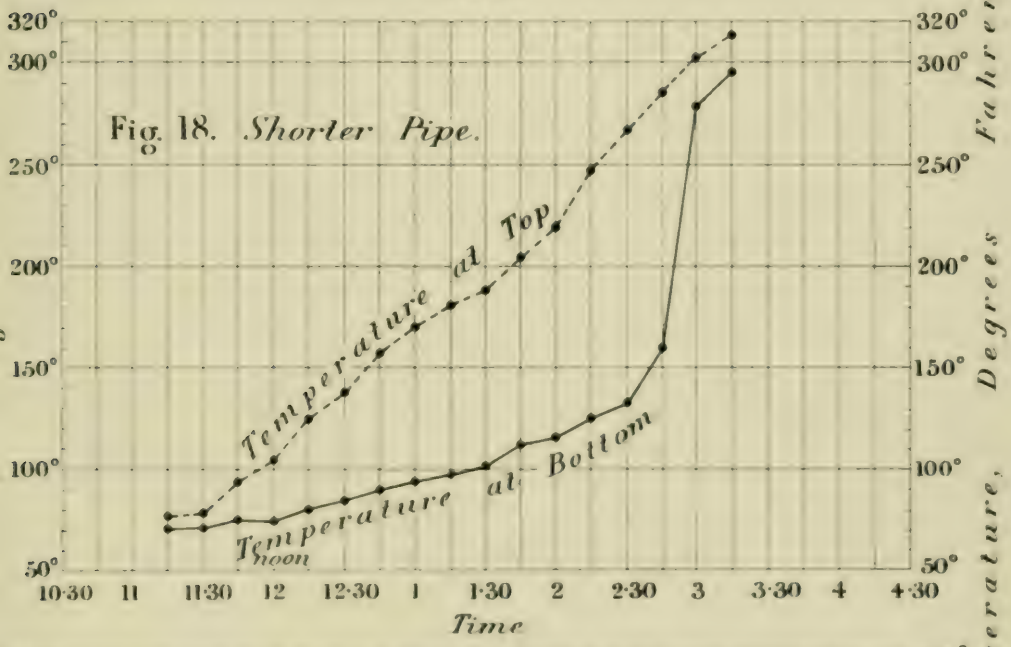
Mechanical Engineers 1891.

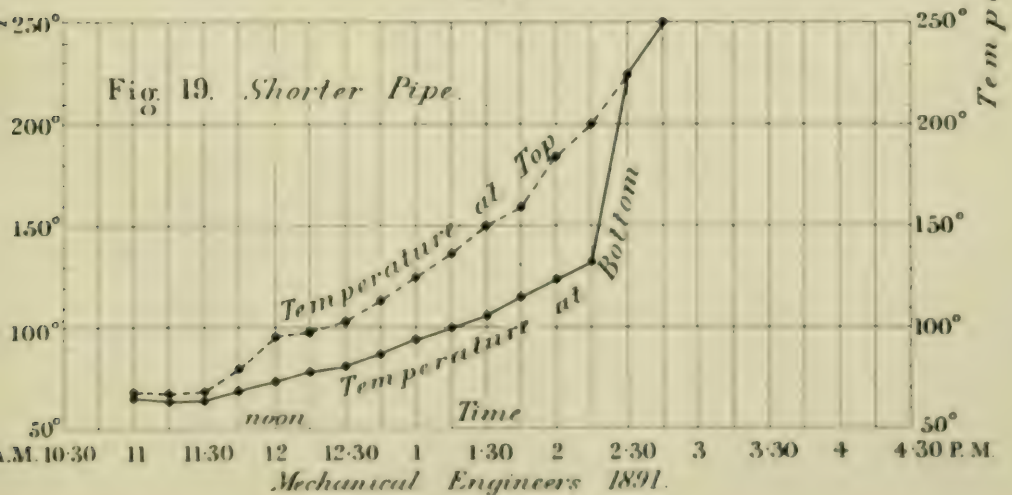
Plate 86.

EXPERIMENTAL MARINE ENGINE. *Plate 87.*

Results of Experiments with Circulating Pipe in Boiler.







Mechanical Engineers 1891.

ALTERNATIVE TESTING MACHINE.

Fig. 22.
Shearing Shackles.
Scale 1/6th

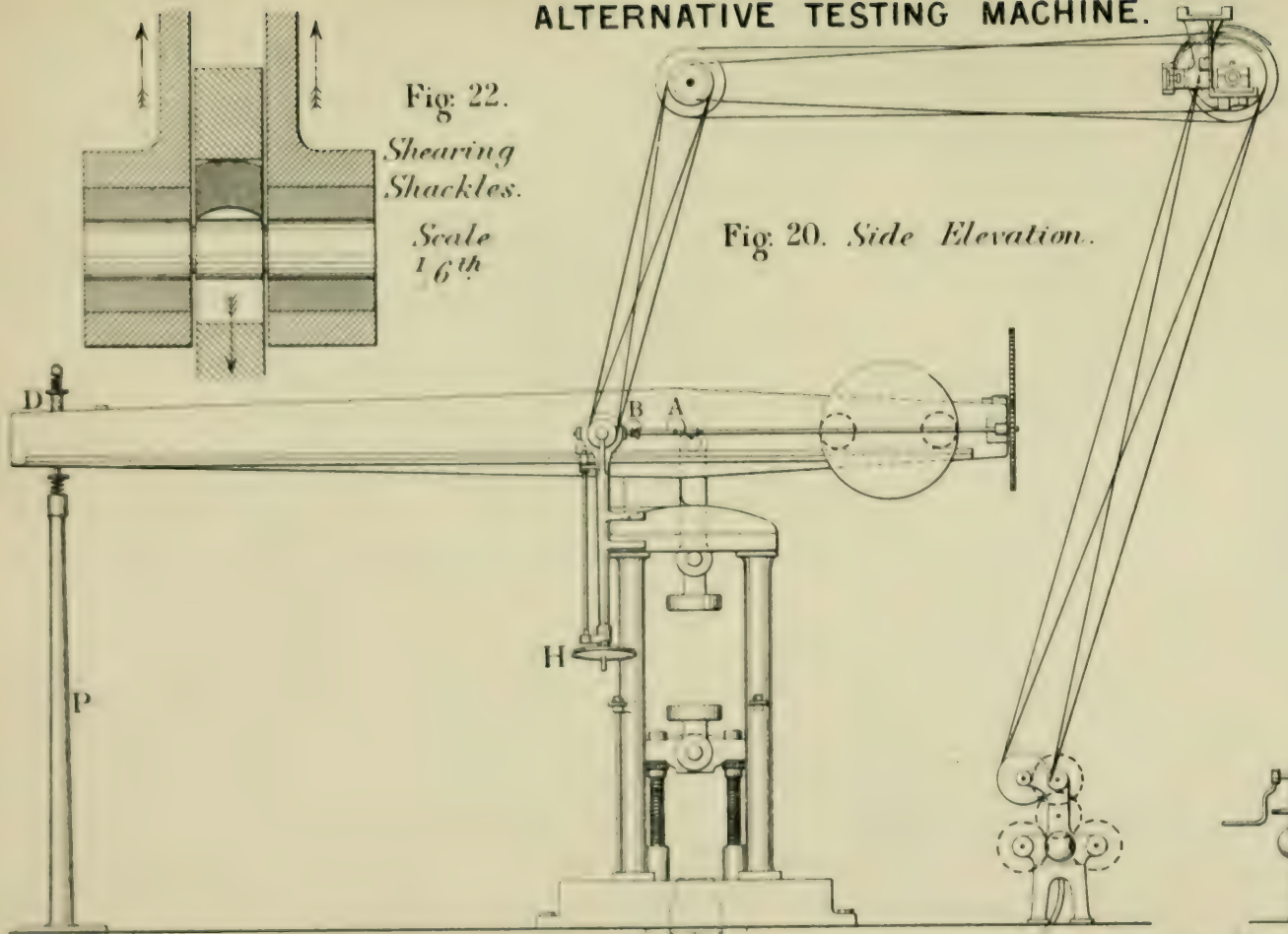


Fig. 20. *Side Elevation.*

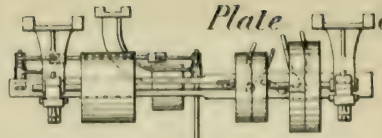
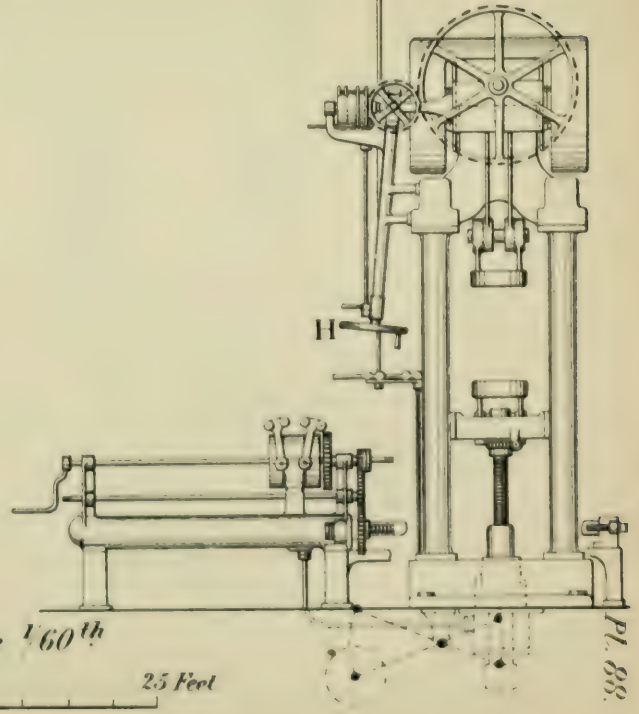


Fig. 21. *End Elevation.*



Mechanical Engineers 1891.

Scale 1/60th

Inches 12 0 5 10 15 20 25 Feet

Pl. 88.

ALTERNATIVE TESTING MACHINE.

Plate 89.

Alternative Centres.

Fig. 23
Transverse Section of Beam

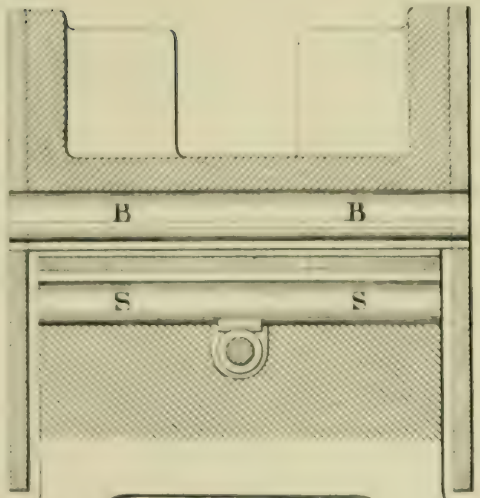
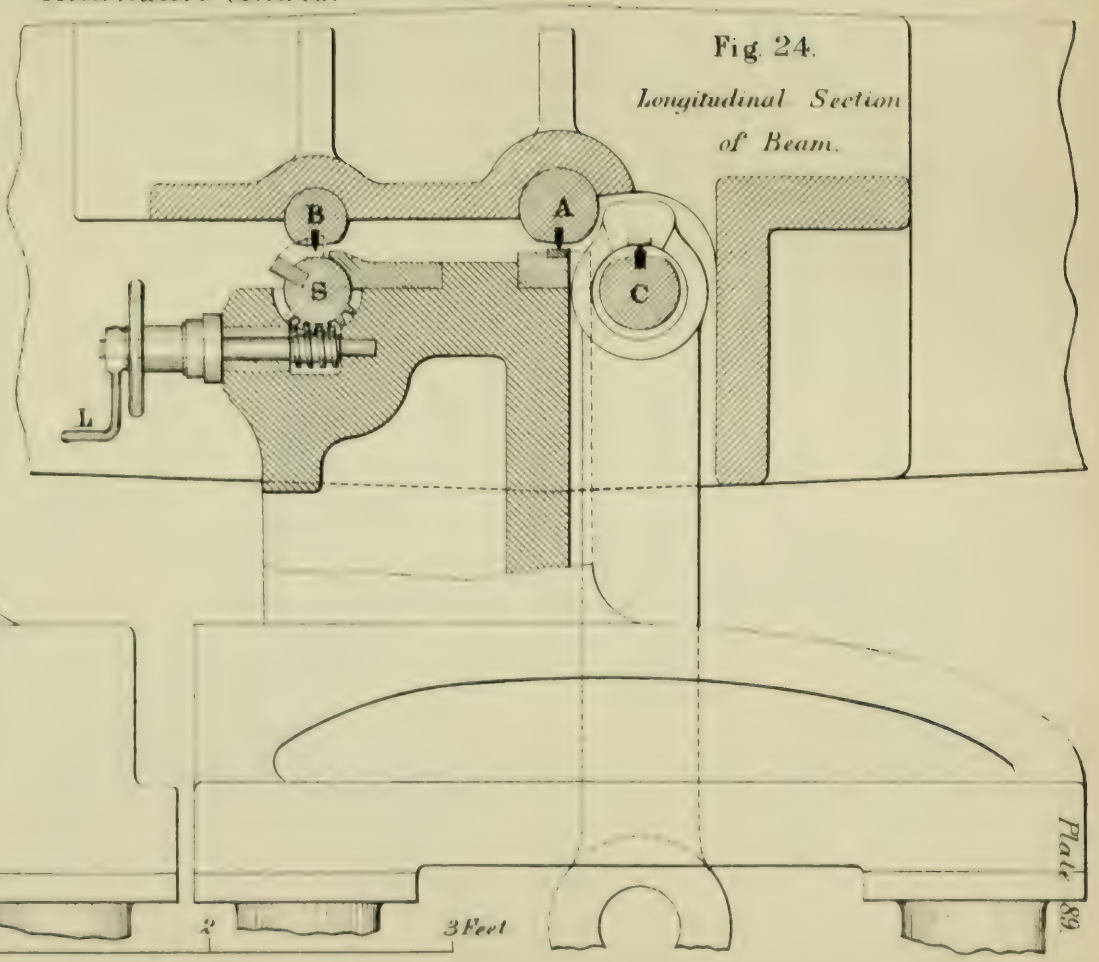


Fig. 24.
Longitudinal Section of Beam.



ALTERNATIVE TESTING MACHINE.

Autographic Test Recorder.

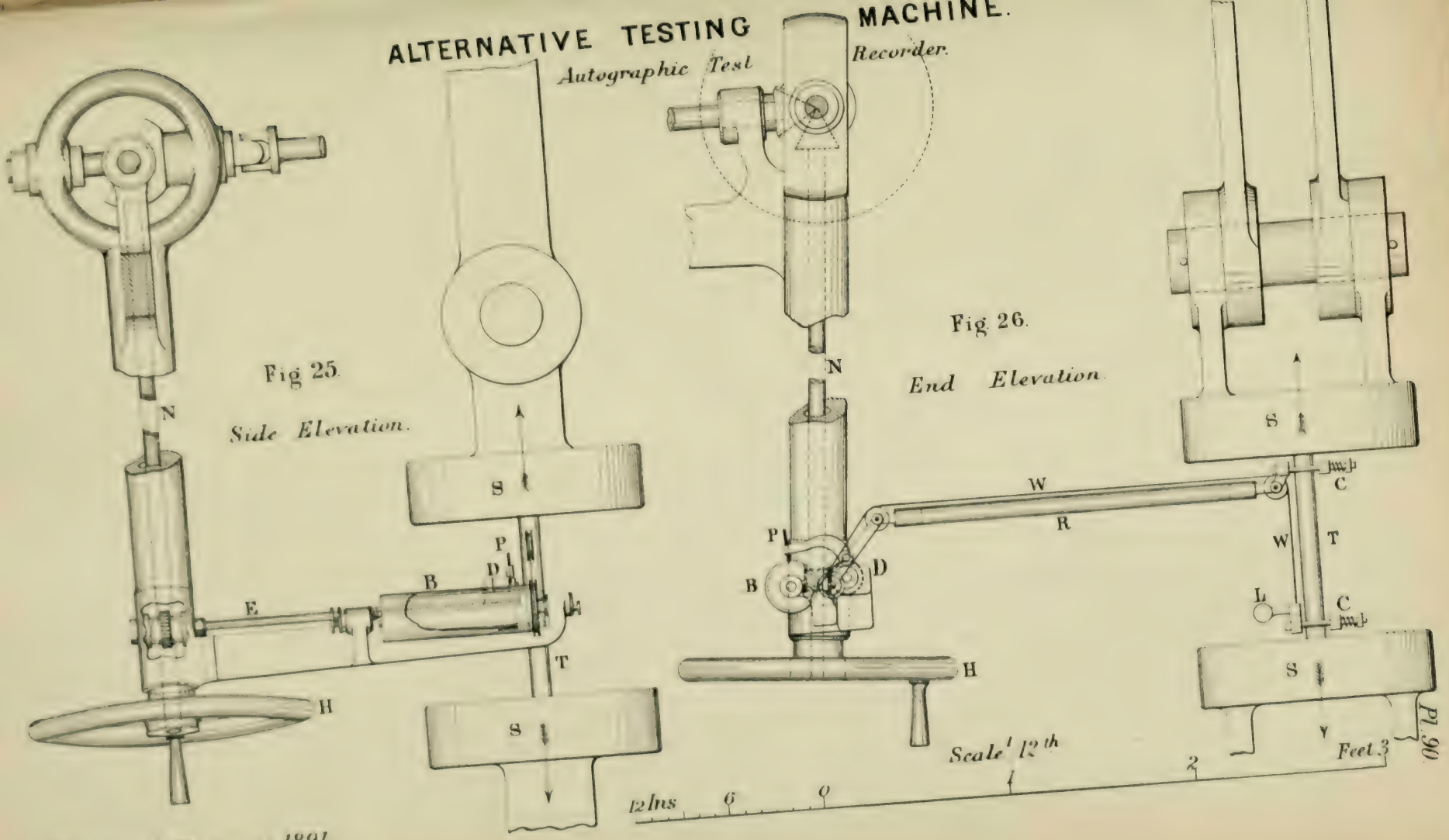


Fig 25. *Side Elevation.*

Fig 26. *End Elevation.*

Scale 1/12th

12 Ins 6 0 1 2 Feet 3

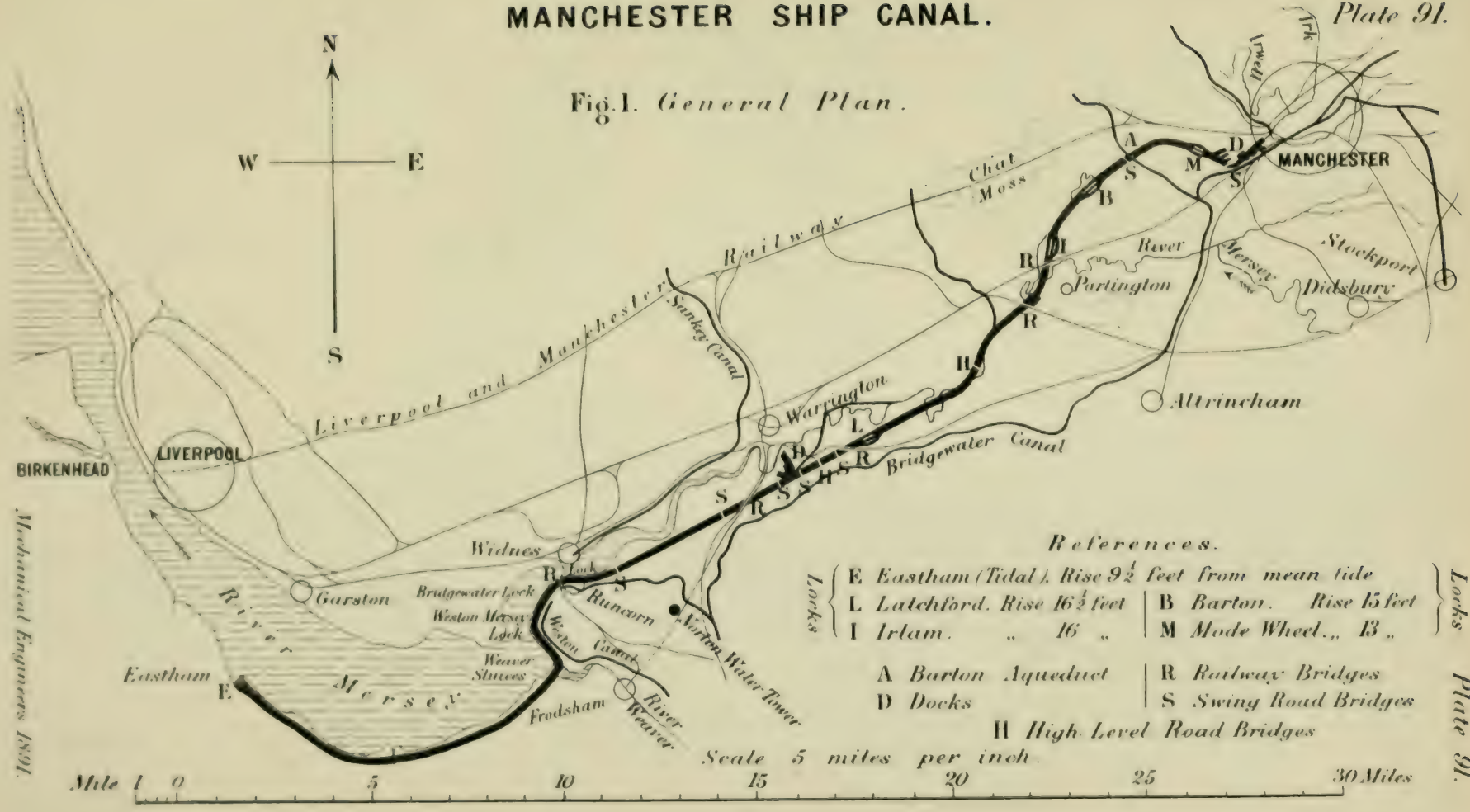
Mechanical Engineers 1891.

Pl. 90

MANCHESTER SHIP CANAL.

Plate 91.

Fig. 1. *General Plan.*



References.

Locks

E *Eastham (Tidal).* Rise 9½ feet from mean tide	
L *Latchford.* Rise 16½ feet	B *Barton.* Rise 15 feet
I *Irlam.* „ 16 „	M *Mode Wheel.* „ 13 „

Locks

A *Barton Aqueduct*	R *Railway Bridges*
D *Docks*	S *Swing Road Bridges*

H *High Level Road Bridges*

Scale 5 miles per inch.

Mile 1 0 5 10 15 20 25 30 Miles

Mechanical Engineer 1891.

Plate 91.

MANCHESTER SHIP CANAL.

Plate 92.

Fig. 2. *Longitudinal Section.*

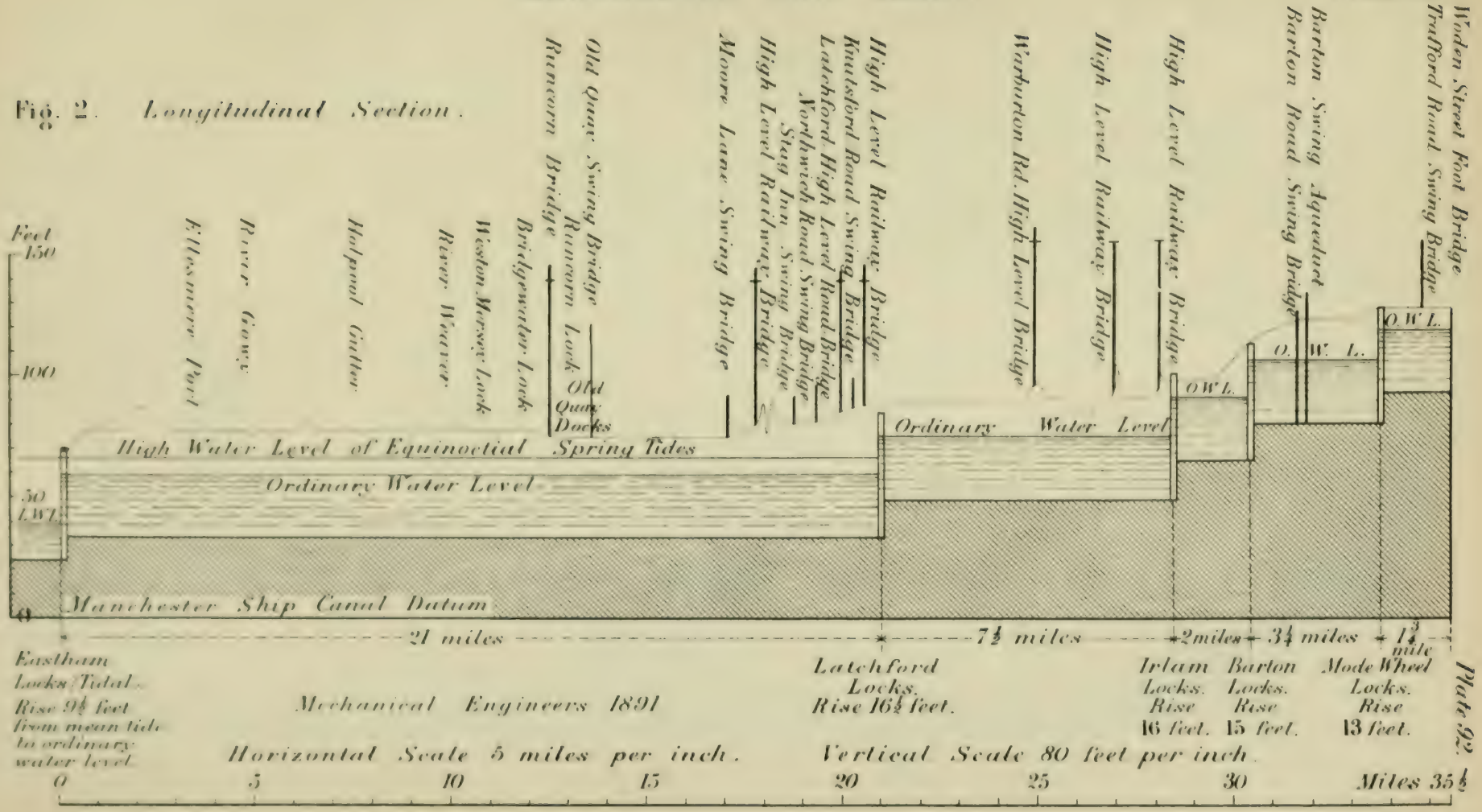
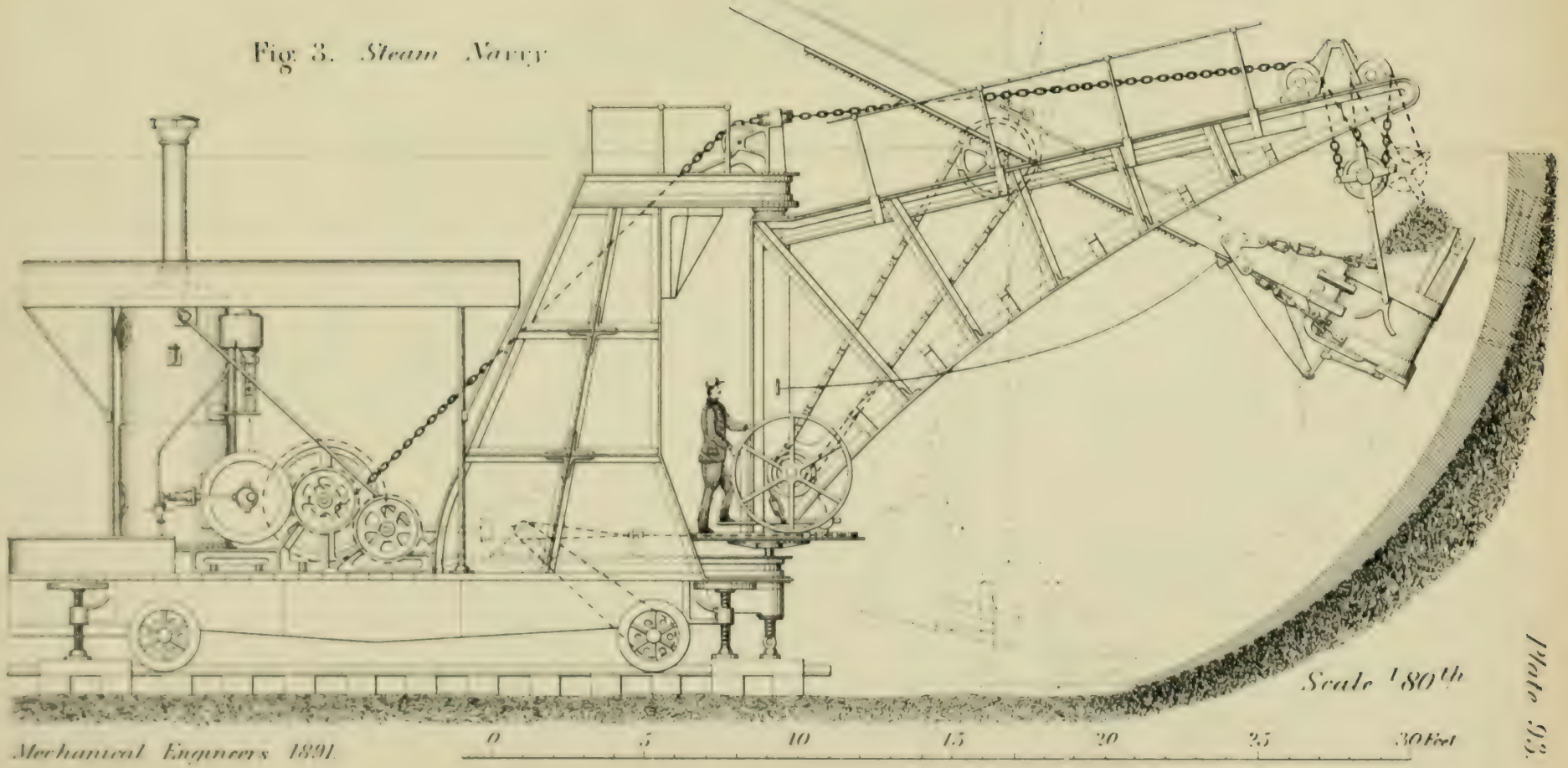


Plate 92.

Fig. 3. *Steam Navvy*



Mechanical Engineers 1891

Plate 23.

MANCHESTER SHIP CANAL.

Plate 94.

Steam - Navvy Bucket
of 2¼ cubic yards capacity.

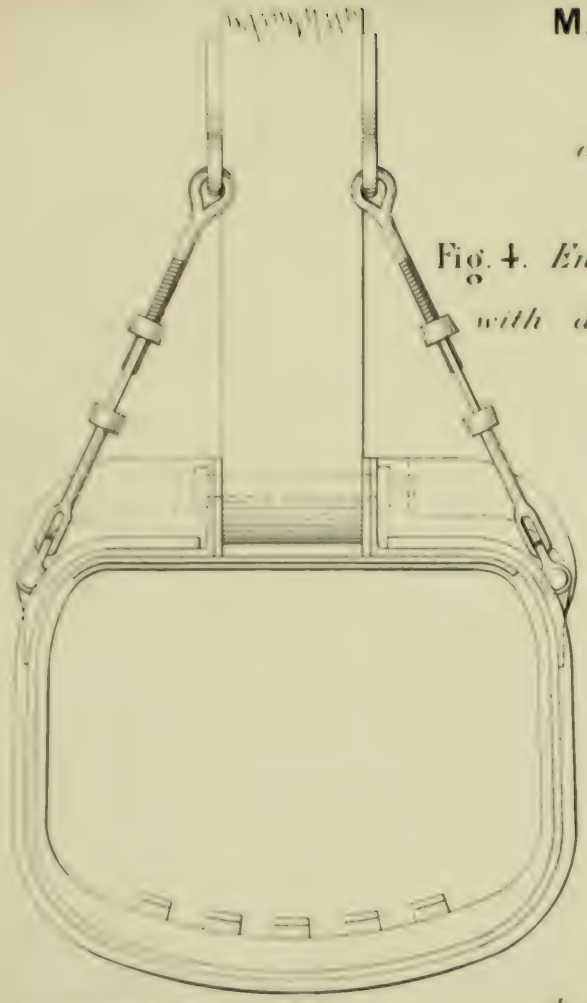


Fig. 4. *End Elevation with door removed.*

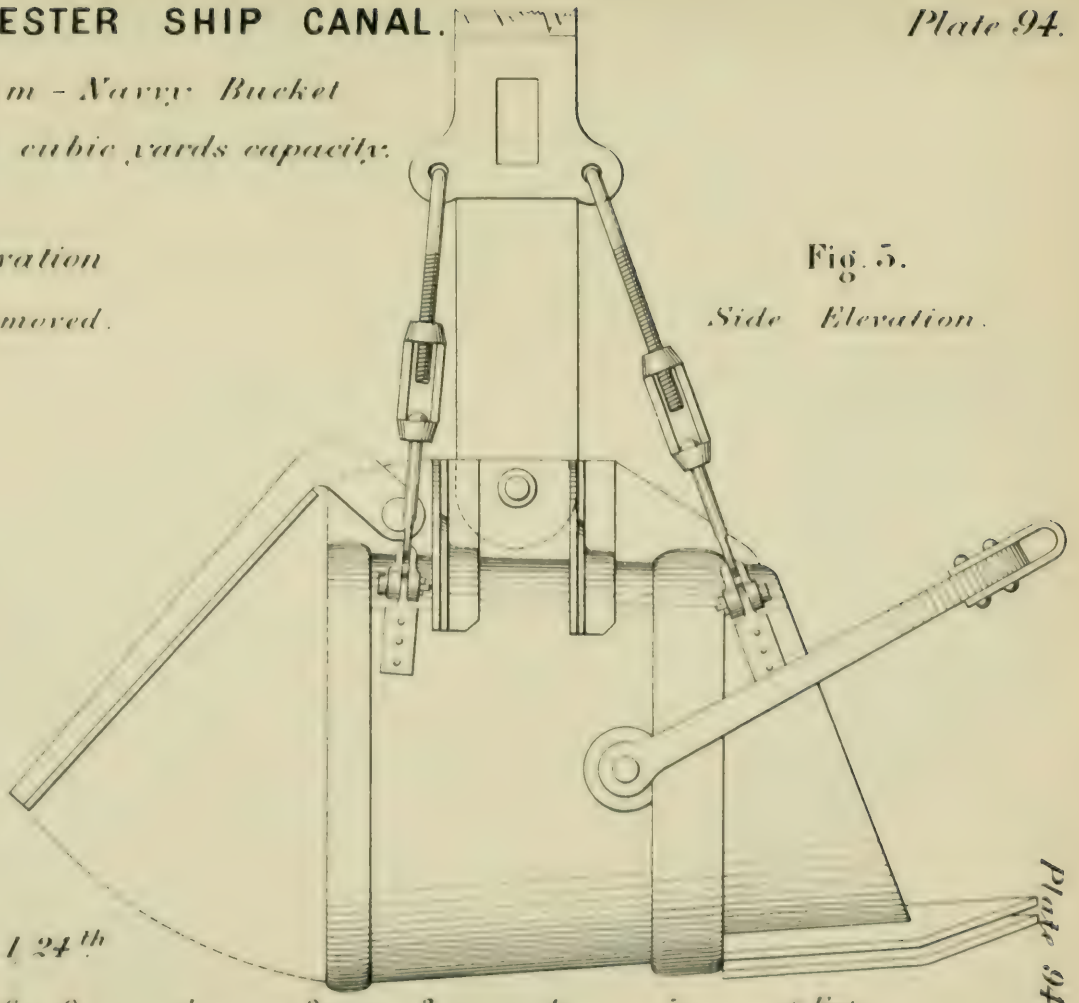


Fig. 5.
Side Elevation.

Scale 1/24th

Inches 12 6 0 1 2 3 4 5 6 Feet

Mechanical Engineers 1891.

Plate 94.

Fig. 6. *Steam Crane Excavator.*

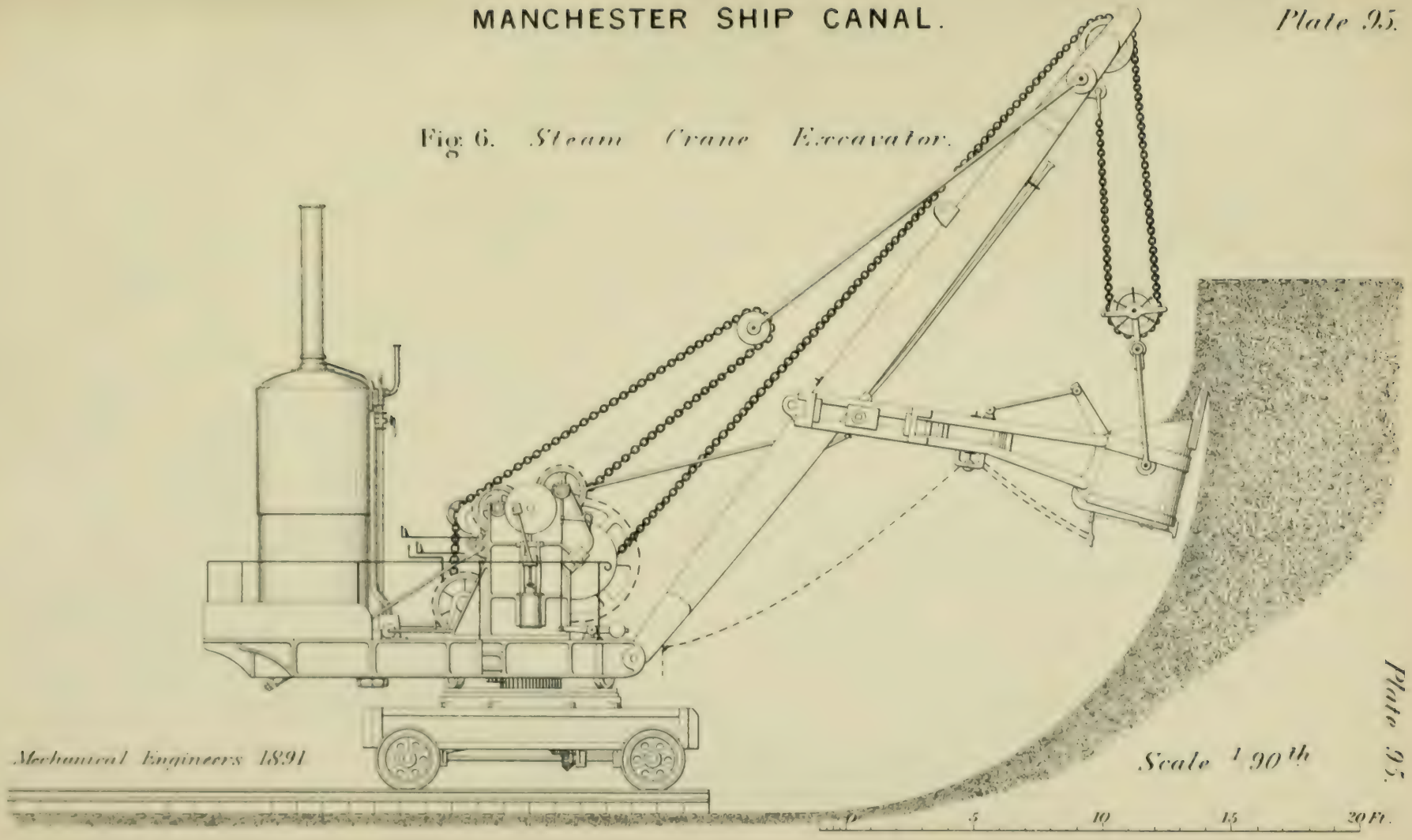


Plate 95.

French Steam Excavator.

Fig. 7.

Sectional Elevation.

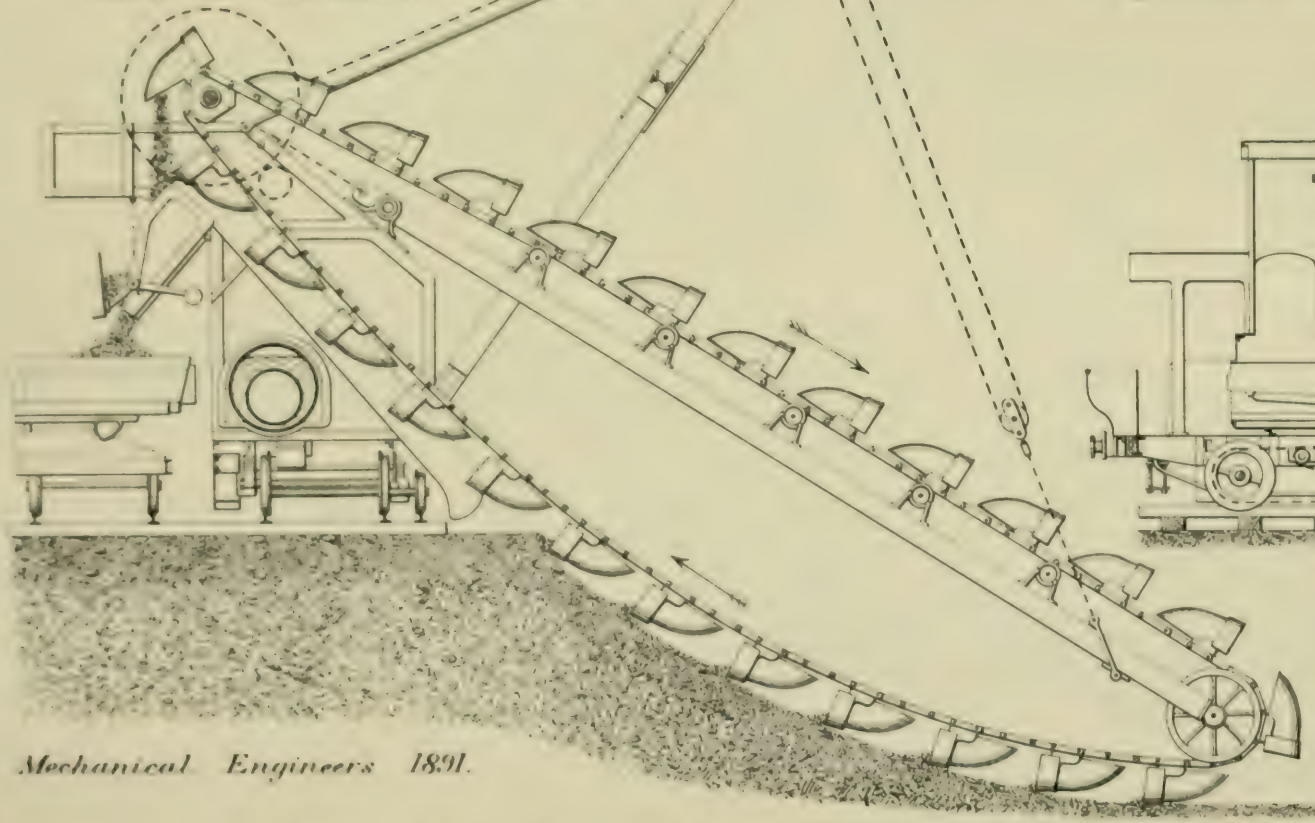
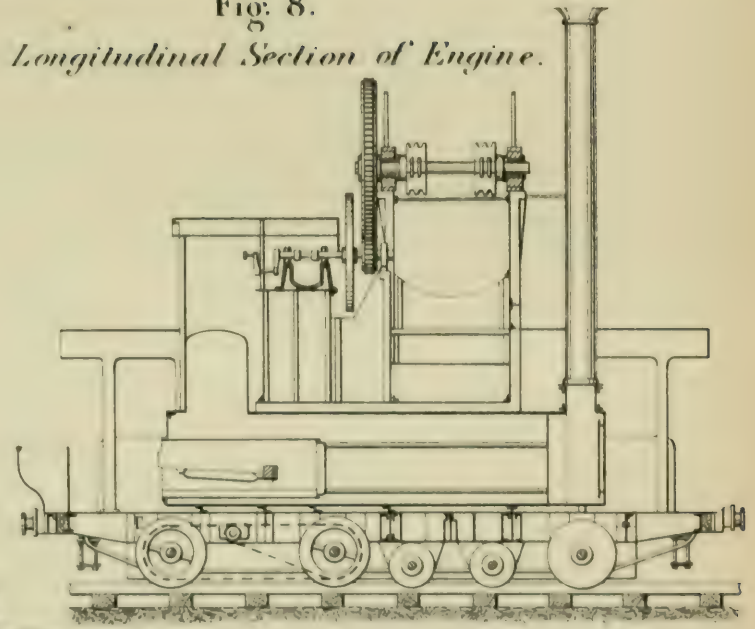


Fig. 8.

Longitudinal Section of Engine.



Mechanical Engineers 1891.

Scale 1/120th

0 5 10 15 20 25 30 35 40 45 50 Feet

Plate 96.

Buckets of French Steam Excavator.

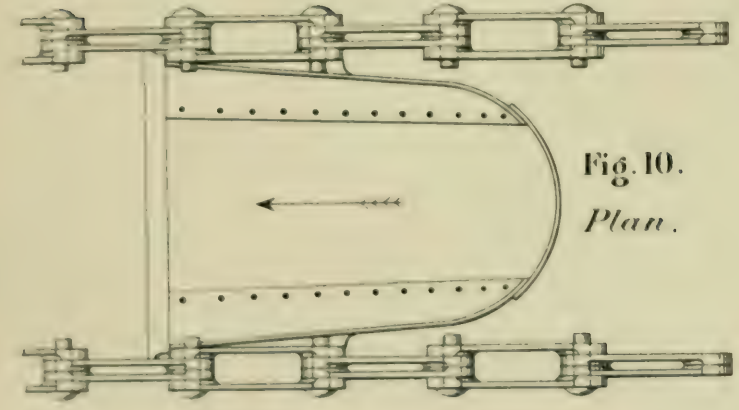


Fig. 10.
Plan.

Fig. 9.
Tipping of Bucket.

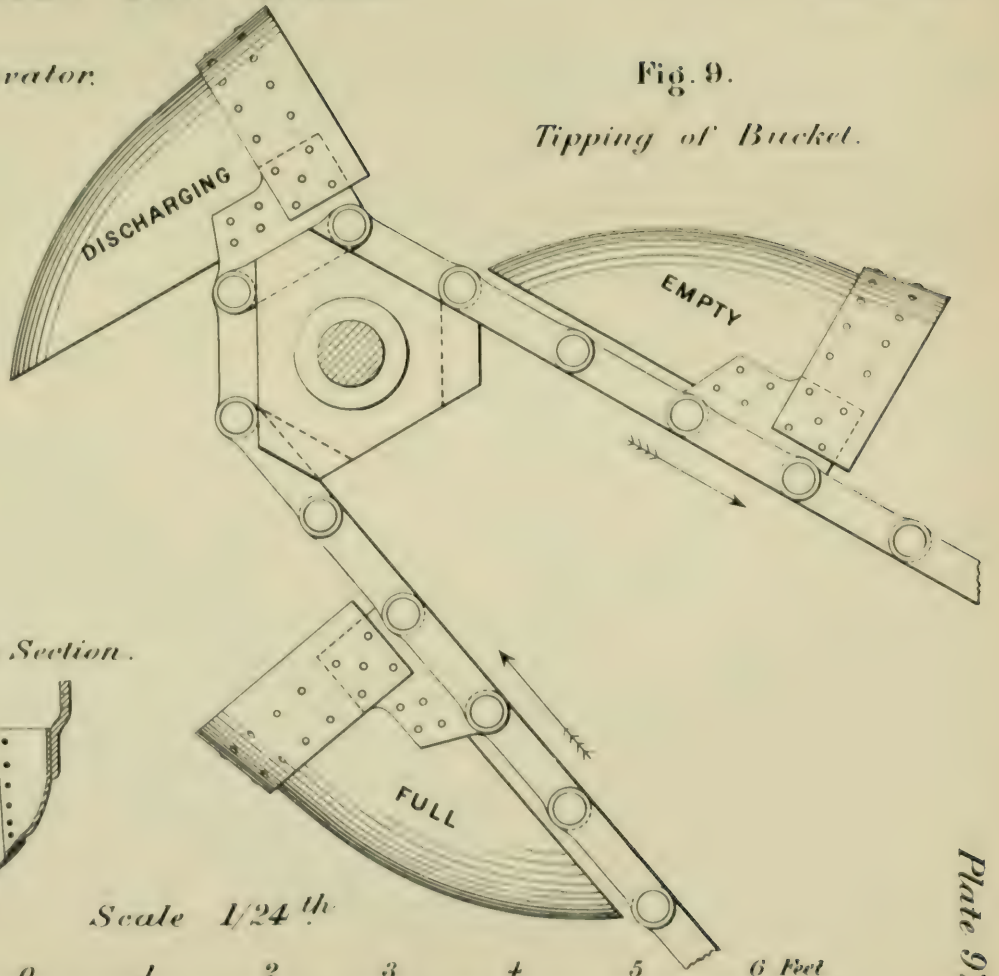


Fig. 11. *End Elevation.*

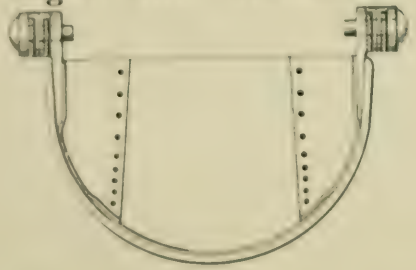
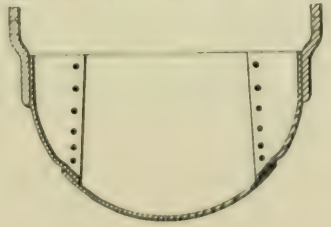


Fig. 12. *Transverse Section.*



Scale 1/24th

Mechanical Engineers 1891.

Plate 97.

German Steam Excavator.

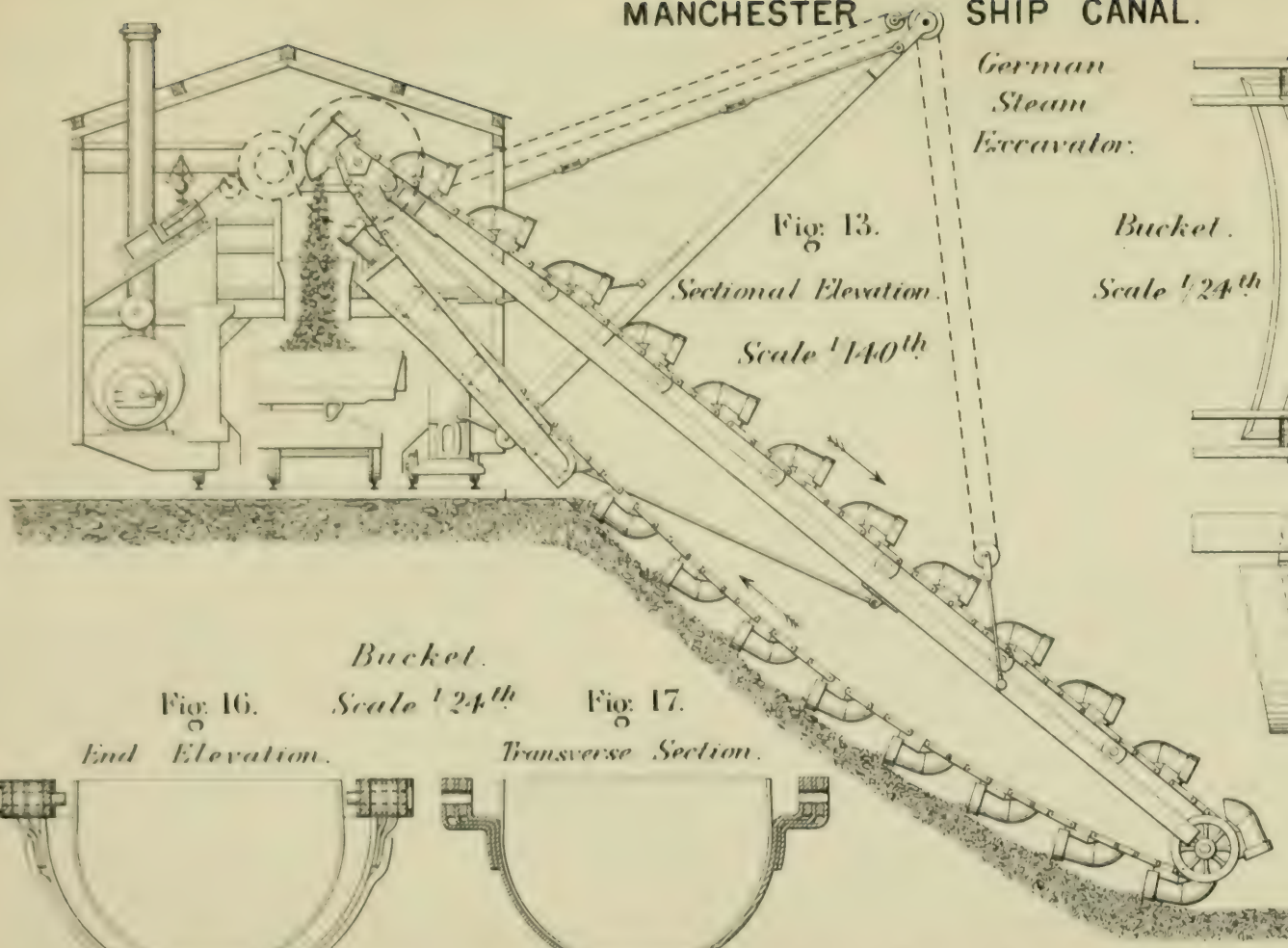
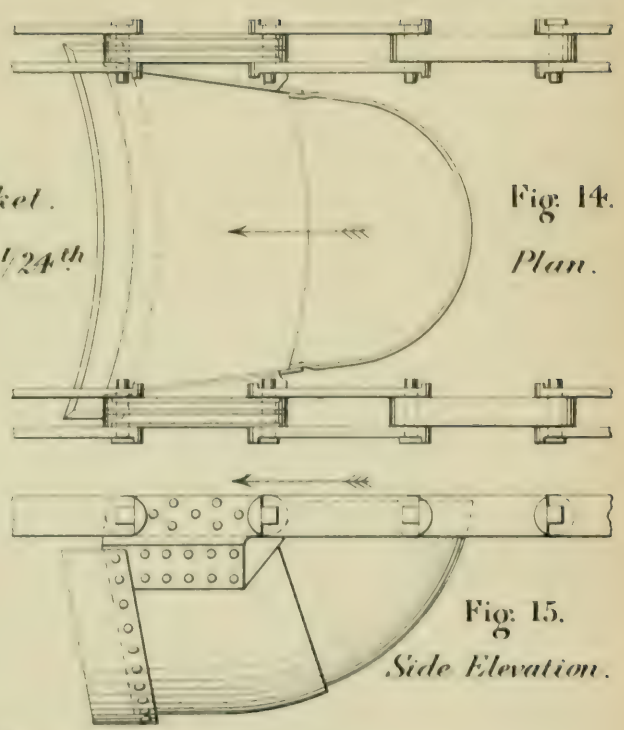


Fig. 13. Sectional Elevation. Scale 1/140th



Bucket. Scale 1/24th

Fig. 14. Plan.

Fig. 15. Side Elevation.

Bucket. Scale 1/24th

Fig. 16. End Elevation.

Fig. 17. Transverse Section.

Scale 1/140th

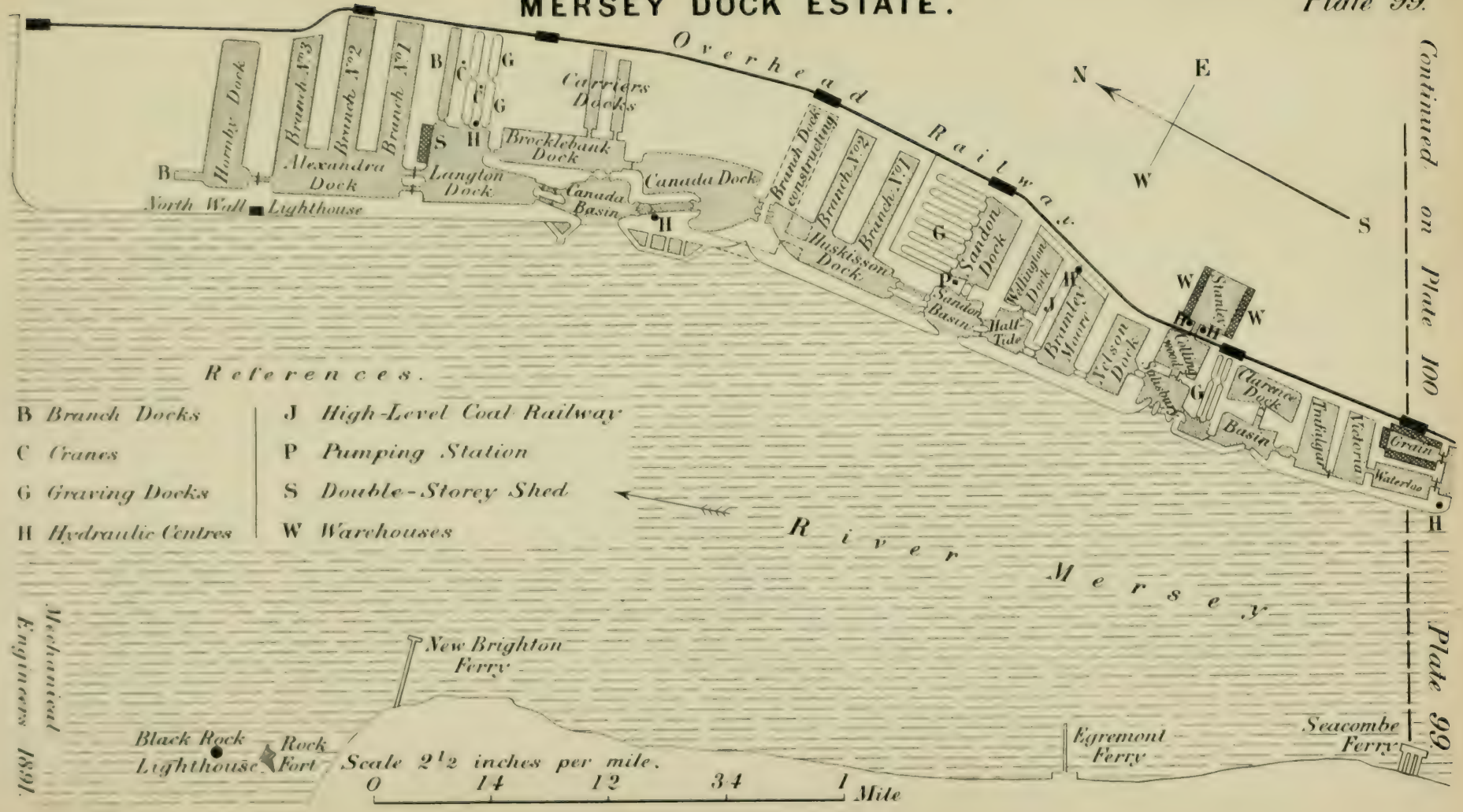
Feet. 0 5 10 15 20 25 30 35 40 45 50

Mechanical Engineers 1891.

Plate 98.

MERSEY DOCK ESTATE.

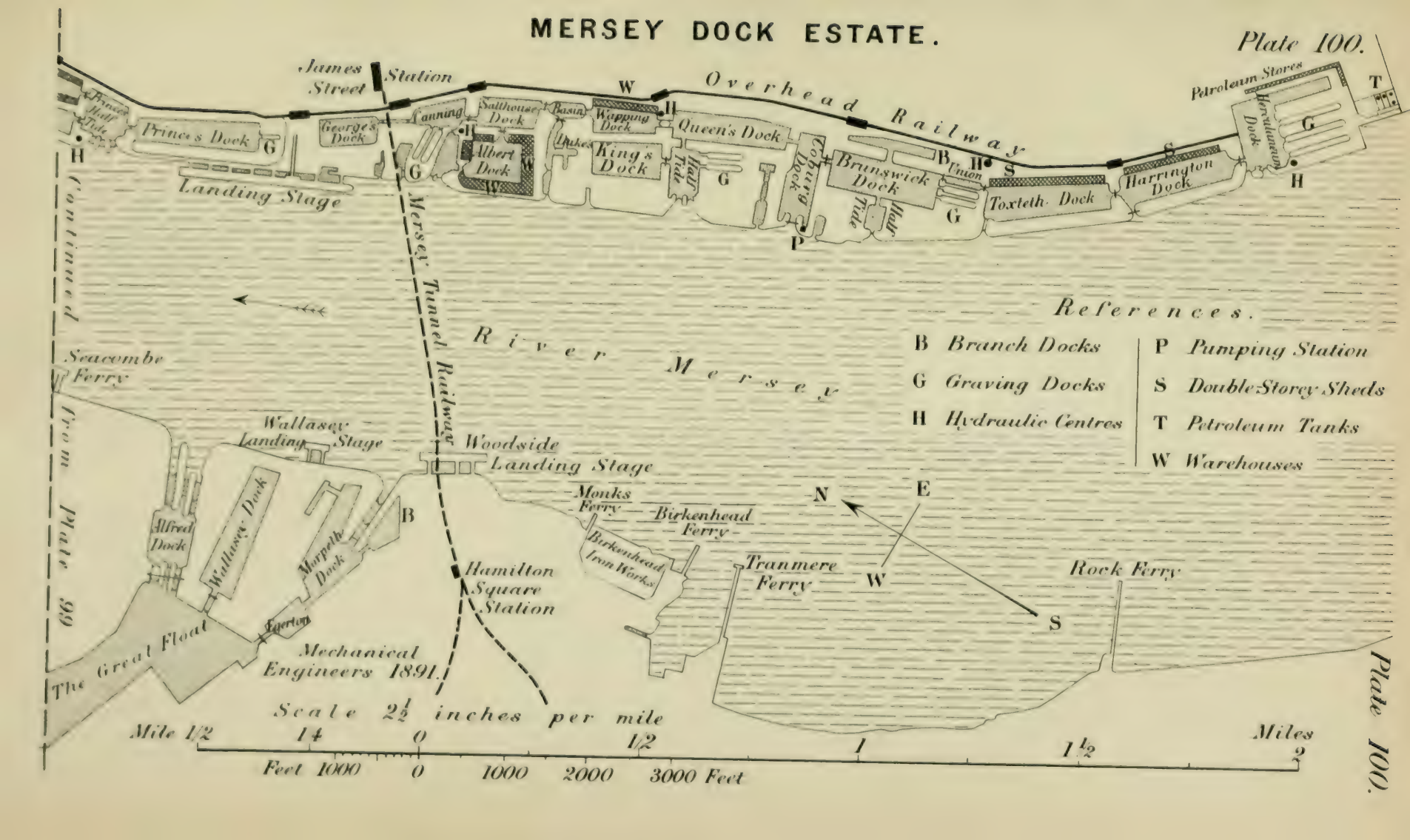
Plate 99.



Continued on Plate 100

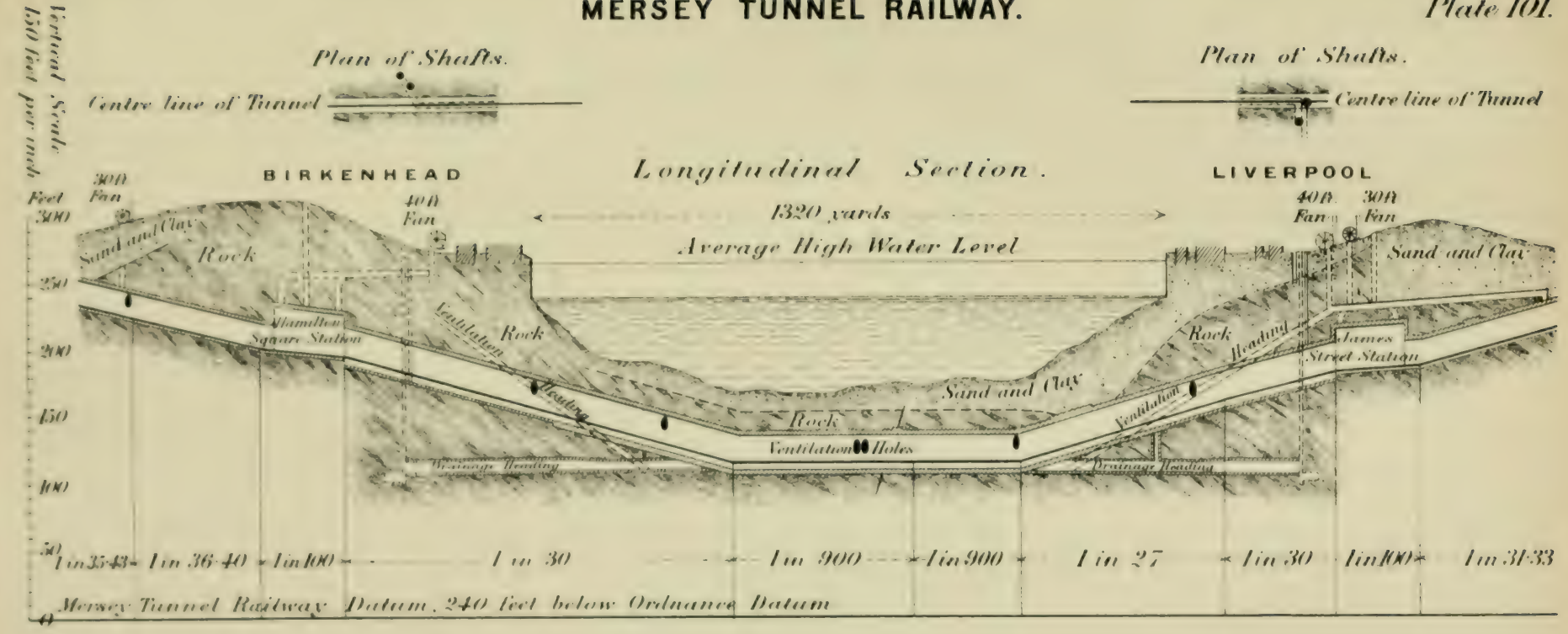
Plate 99.

Mechanical Engineers 1891.


MERSEY DOCK ESTATE.
Plate 100.
James Street Station
Overhead Railway
Petroleum Stores
Prince's Dock
George's Dock
Canning Dock
Salthouse Dock
Basin
Wapping Dock
Queen's Dock
Albert Dock
King's Dock
Half Tide
Coburg Dock
Brunswick Dock
Union
Toxteth Dock
Harrington Dock
Herculaneum Dock
Landing Stage
Mersey Tunnel Railway
River Mersey
Seacombe Ferry
Wallasey Landing Stage
Woodside Landing Stage
Monks Ferry
Birkenhead Ferry
Birkenhead Iron Works
Tranmere Ferry
Rock Ferry
Alfred Dock
Wallasey Dock
Morpeth Dock
Egerton
Hamilton Square Station
The Great Float
Mechanical Engineers 1891.
References.
B Branch Docks
G Graving Docks
H Hydraulic Centres
P Pumping Station
S Double-Storey Sheds
T Petroleum Tanks
W Warehouses
N
E
W
S
Scale 2½ inches per mile
Mile 1/2 1 1/2 0 1/2 1 1½ Miles 2
Feet 1000 0 1000 2000 3000 Feet
Plate 99
Plate 100.

MERSEY TUNNEL RAILWAY.

Plate 101.



Mechanical Engineers 1891.

Horizontal Scale 400 yards per inch.

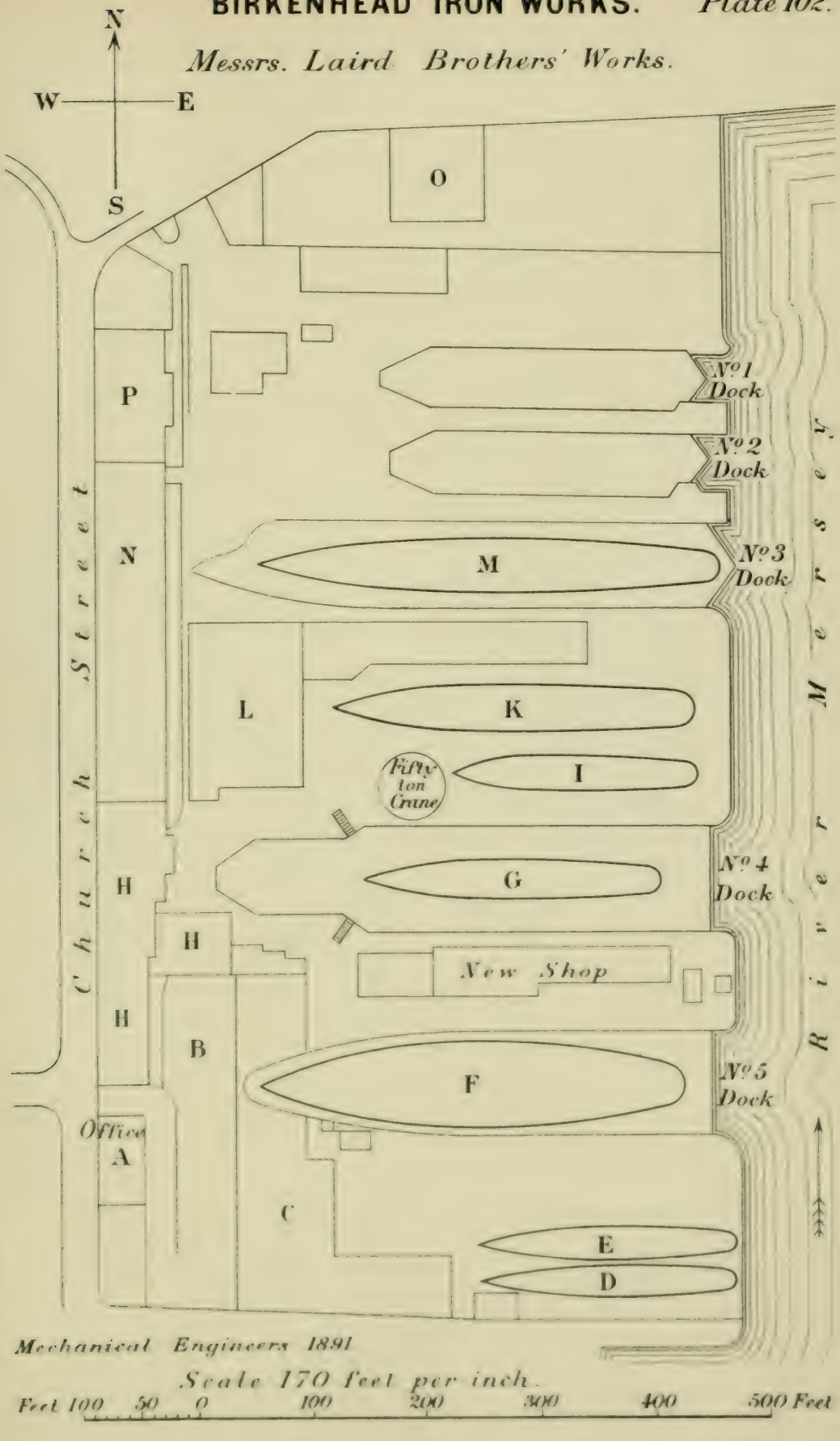
Yards 100 0 500 1000 1500 2000 2500 Yards

0 $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 $1\frac{1}{4}$ Mile $1\frac{1}{2}$

Plate 101.

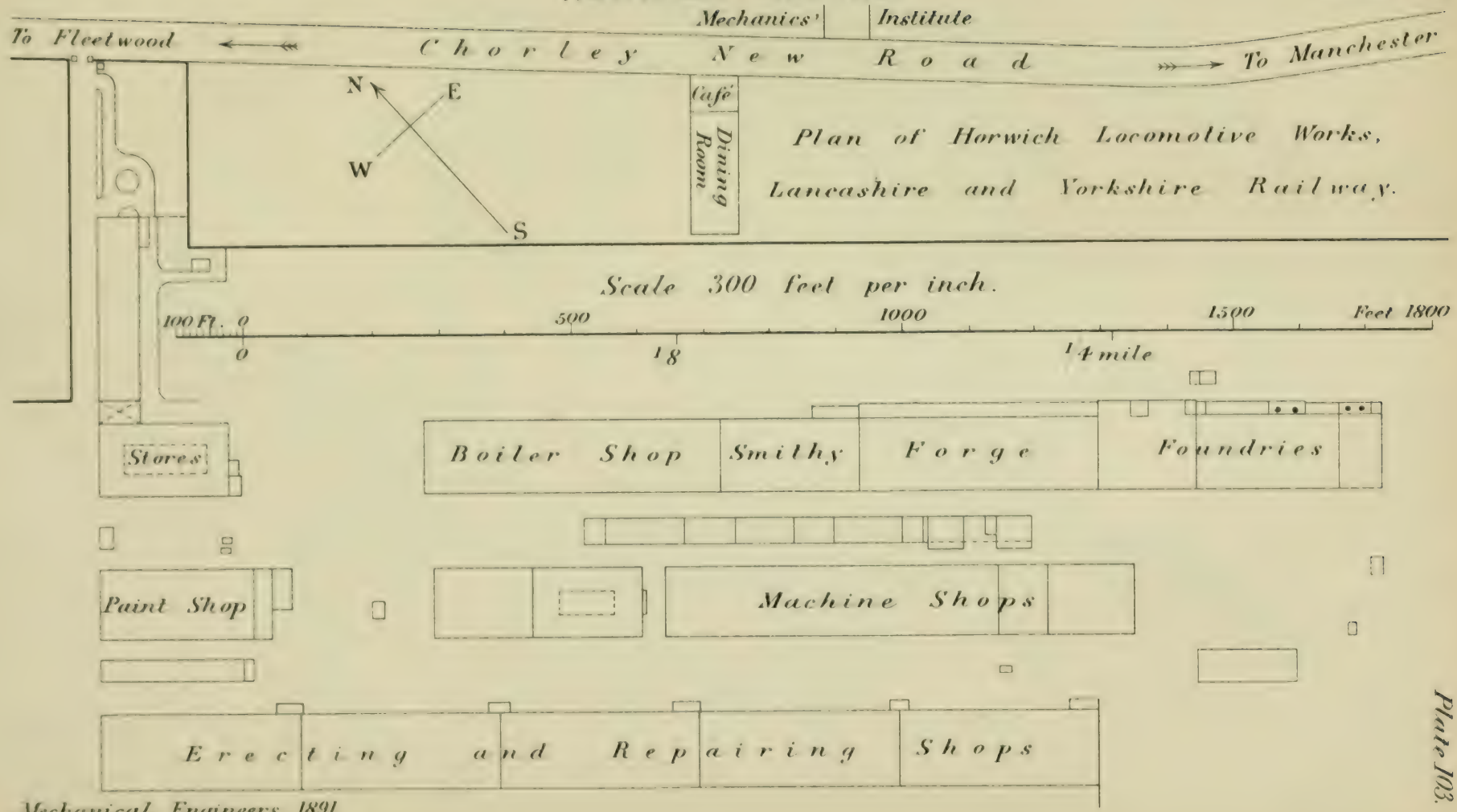
BIRKENHEAD IRON WORKS. *Plate 102.*

Messrs. Laird Brothers' Works.



HORWICH WORKS.

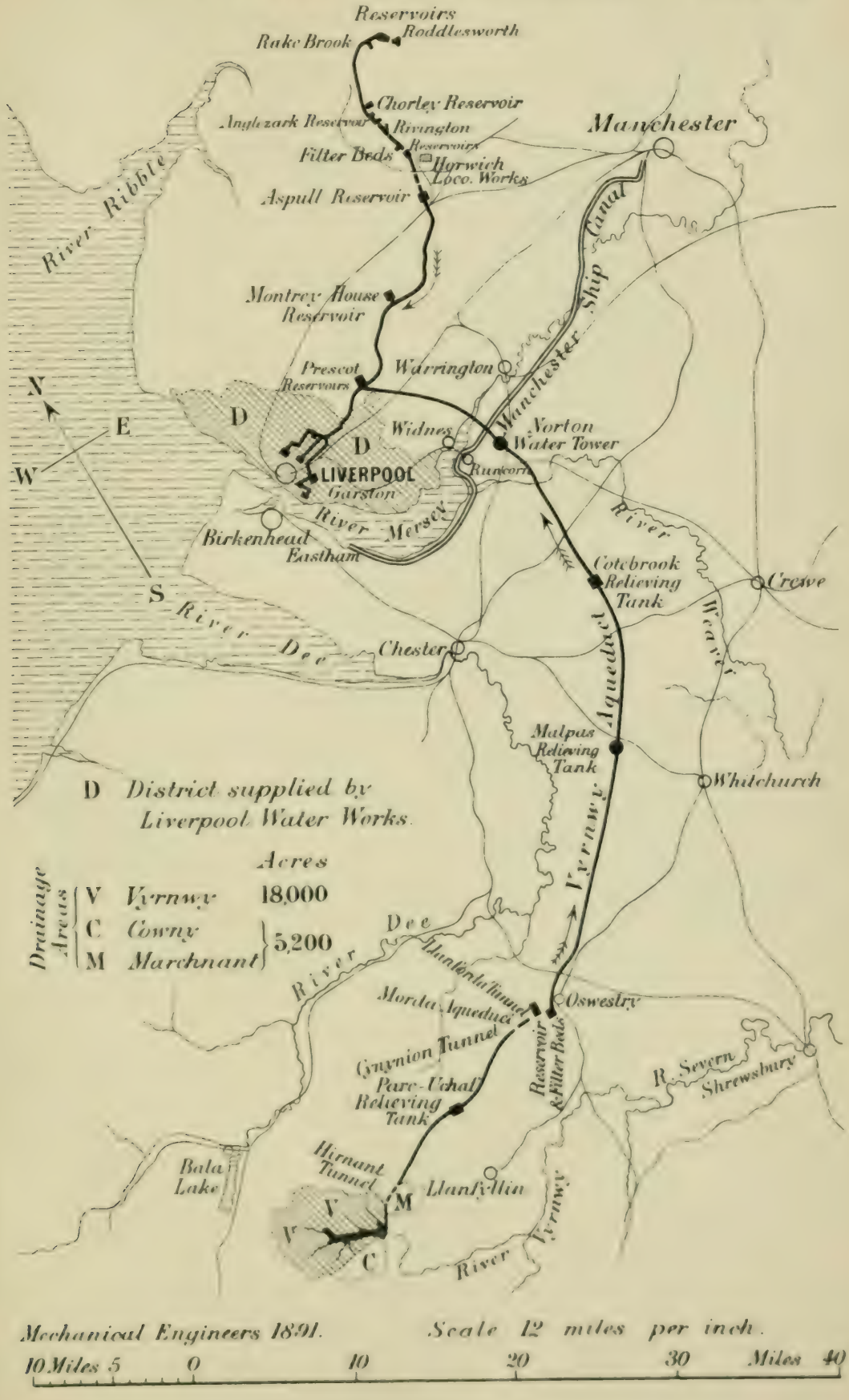
Plate 103.



Mechanical Engineers 1891.

Plate 103.

LIVERPOOL WATER WORKS. *Plate 104.*



Mechanical Engineers 1891. *Scale 12 miles per inch.*

10 Miles 5 0 10 20 30 Miles 40

LIVERPOOL WATER WORKS.

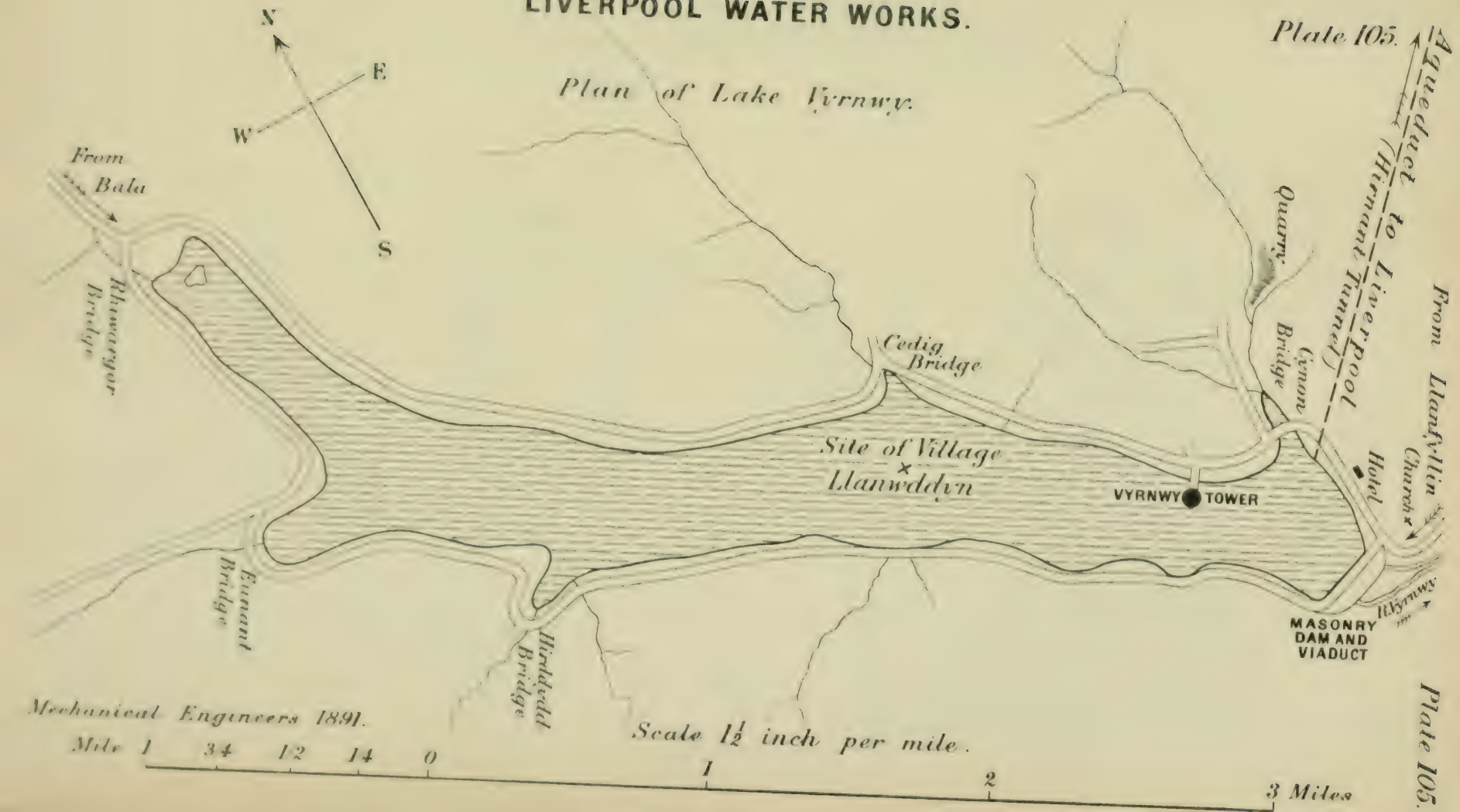
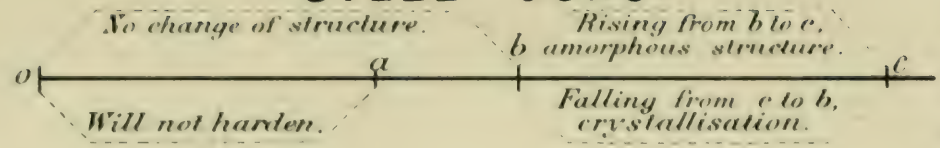


Plate 105.

STEEL GUNS.

Plate 106.

Fig. 1. *Chernoff's scale for Steel Temperature.*



o zero of scale.
a dark cherry red.
b red, but not sparkling.
c melting point.

Fig. 2. *Vertical Section of Heating Furnace.*

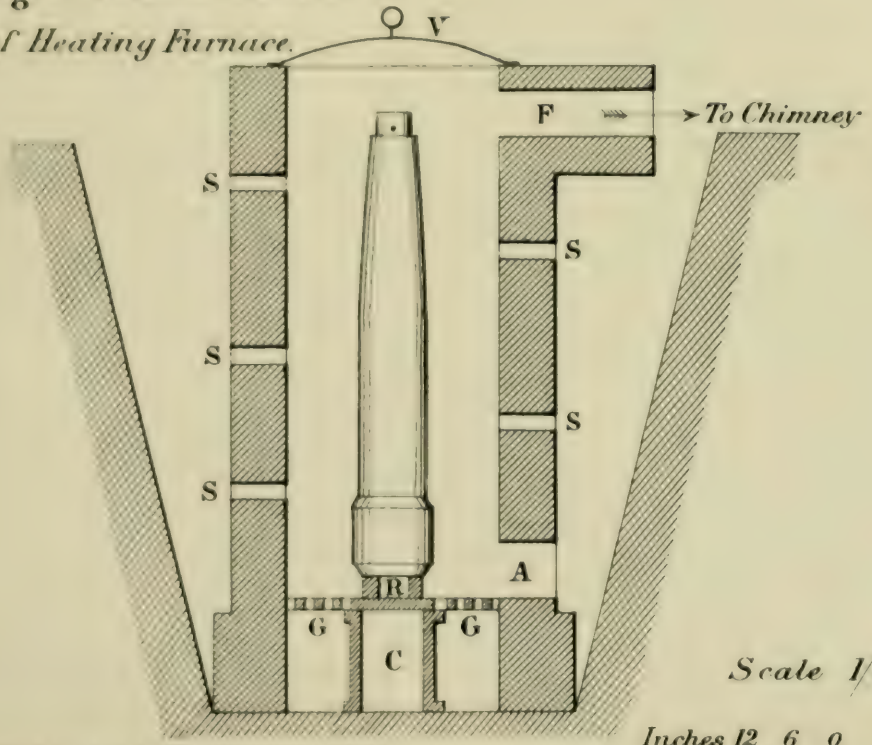
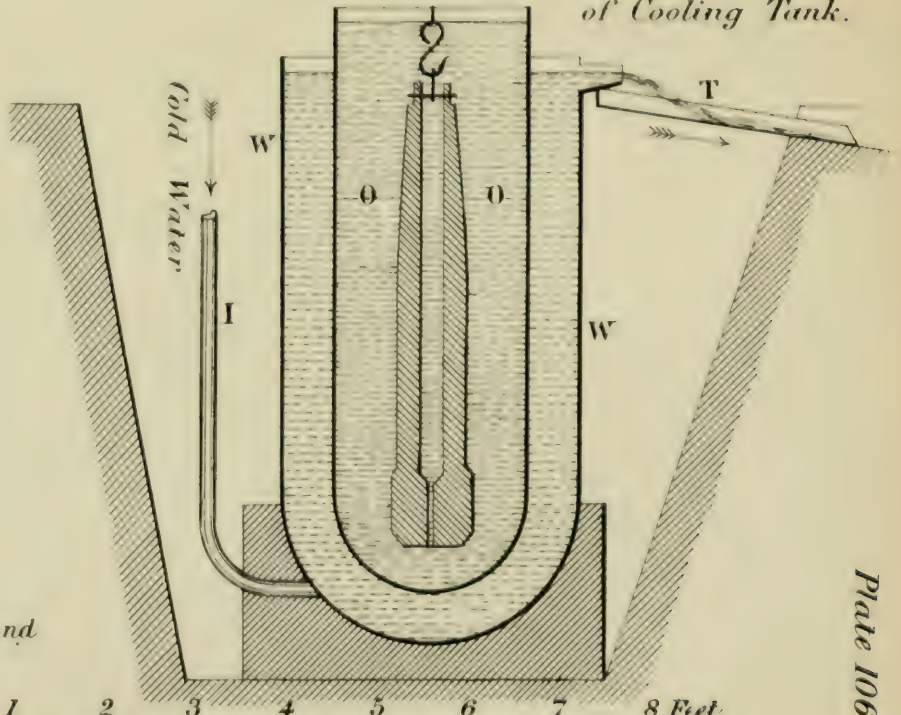


Fig. 3. *Vertical Section of Cooling Tank.*



Scale 1/32nd

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet

Mechanical Engineers 1891.

Plate 106.

Institution of Mechanical Engineers.

PROCEEDINGS.

October 1891.

The Autumn Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 28th October 1891, at Half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Council had presented the cordial Thanks of the Institution, engrossed upon vellum and framed, together with a Time-piece and Inkstand with suitable inscriptions, to Mr. Henry H. West, in recognition of his energetic and obliging exertions in maturing and carrying out as the Honorary Secretary the various arrangements for the recent Summer Meeting in Liverpool, whereby the success of the Meeting had been ensured and the enjoyment of the Members enhanced.

The President announced that the Ballot Lists for the election of New Members, Associates, and Graduates, had been opened by a committee of the Council, and that the following thirty-nine candidates were found to be duly elected:—

MEMBERS.

John Edward Lloyd Barnes,	Liverpool.
John Ebenezer Bousfield,	London.
Edwin Henry George Brewster,	London.
Ronald Hope Bridie,	London.
William Broadbent,	Huddersfield.
James Butler,	Halifax.

William Charles Carter,	London.
Myles Cooper,	Manchester.
William James Douglass,	Blaydon-on-Tyne.
James Alfred Ewing, F.R.S.,	Cambridge.
Finlay Finlayson,	Coatbridge.
Richard Hanson,	Bradford.
Raymond Hillman Hornbrook,	Hong Kong.
Henry Albert Hoy,	Horwich.
Charles Arbuthnot Hubback,	St. Albans.
Charles Frederick Jones,	Bombay.
Bertrand Thornton Knight,	Sandakan.
James Manson,	Kilmarnock.
Robert Thomas Middleton,	Bombay.
William Naylor,	Wolverhampton.
Thomas Parker,	Wolverhampton.
John George Robinson,	Limerick.
Alphonse Louis Sellier,	Trinidad.
Robert Alexander Sloan,	Liverpool.
William Stringer,	Manchester.
John Vicars,	Newton-le-Willows.
Julius E. Waterous,	Brantford, Ontario.

ASSOCIATES.

Frederick Heathcote Carter,	Manchester.
George Henry Jennings,	London.
Hugh Monie, Jun.,	Bombay.
Thomas Thomson Rankin,	Coatbridge.
Bertram Rochfort,	London.
William Charles Rowcliffe,	London.
Edmund Wiseman,	Luton.

GRADUATES.

Walter Edward Butcher,	Brighton.
Martin Gordon Duncan,	London.
Edward Sinclair Bremner Hughes,	Helensburgh.
Frederic William Jordan,	London.
John Leonard Vaizey,	London.

The President announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

Joseph Tomlinson, . . .	London.

VICE-PRESIDENTS.

Sir James N. Douglass, F.R.S., .	London.
Arthur Paget, ...	Loughborough.

MEMBERS OF COUNCIL.

Benjamin A. Dobson, . . .	Bolton.
John G. Mair-Rumley, . .	London.
Henry D. Marshall, . . .	Gainsborough.
Edward B. Marten, . . .	Stourbridge.
J. Hartley Wicksteed, . .	Leeds.

Of these the following offered themselves for re-election:—

VICE-PRESIDENT.

Sir James N. Douglass, F.R.S., .	London.

MEMBERS OF COUNCIL.

Benjamin A. Dobson, . . .	Bolton.
John G. Mair-Rumley, . .	London.
Henry D. Marshall, . . .	Gainsborough.
J. Hartley Wicksteed, . .	Leeds.

The following nominations had also been made by the Council for the election at the Annual General Meeting:—

PRESIDENT.

William Anderson, D.C.L., F.R.S.,	Woolwich.

VICE-PRESIDENT.

Edward B. Marten, . . .	Stourbridge.

Election as Member.	MEMBERS OF COUNCIL.	
1864.	William Kirtley, . .	London.
1865.	Francis C. Marshall, .	Newcastle-on-Tyne.
1866.	Robert H. Humphrys, .	London.
1868.	William Dean, . . .	Swindon.
1871.	James Platt, . . .	Gloucester.
1881.	John A. F. Aspinall, . .	Bolton.
1885.	Thomas Mudd, . . .	West Hartlepool.

The President reminded the Meeting that according to the Rules of the Institution any Member was now entitled to add to the list of candidates.

Mr. Henry Chapman made the following nomination:—

MEMBER OF COUNCIL.

1878.	Arthur Greenwood, . .	Leeds.

The President announced that the foregoing names would accordingly constitute the nomination list for the election of officers at the Annual General Meeting. It would be observed that the list did not include the name of Mr. Arthur Paget, one of the two Vice-Presidents retiring, who was prevented by ill health, he was sorry to say, from offering himself for re-election.

The following Paper was then read and discussed:—

"On some details in the Construction of modern Lancashire Boilers";
by Mr. Samuel Boswell, of Manchester.

At Ten o'clock the Meeting was adjourned to the following evening. The attendance was 108 Members and 61 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Thursday, 29th October 1891, at Half-past Seven o'clock p.m.; Joseph Tomlinson, Esq., President, in the chair.

The following Paper was read and discussed:—

"First Report to the Alloys Research Committee"; by Professor W. C. Roberts-Austen, C.B., F.R.S.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers, for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at Ten o'clock. The attendance was 72 Members and 57 Visitors.

ON SOME DETAILS IN THE CONSTRUCTION OF MODERN LANCASHIRE BOILERS.

By Mr. SAMUEL BOSWELL, of Manchester.

The great advance in engineering, due to the use of higher steam-pressure, has brought about numerous improvements in the design and construction of Lancashire Boilers, which however in many points are still far from perfect; and the object of the present paper is to draw attention to some of the imperfections yet remaining, and to indicate how they may be remedied, wholly or partially, and probably without increasing the present cost of the best work. It will be assumed that the boilers are intended for working under the conditions usually met with in Lancashire, under which they have been found to answer well: namely, fed with water not of the best, and fired with the slack generally used as fuel. The subject will be dealt with under the general headings of material, construction, and testing.

Steel.—At the present time the most suitable material that can be used for the construction of Lancashire boilers is believed to be mild steel manufactured by the Siemens-Martin open-hearth process, which is preferred to that made on the Bessemer process because it is generally found to be more homogeneous and reliable. When mild steel was first introduced, it was of a somewhat unreliable nature, inasmuch as its component ingredients, in their relation to each other and their influence on the whole, were not so fully understood as at present; but even in the early stage of mild-steel manufacture on a smaller scale than the present, careful endeavours were made to produce a material as free from mechanical defects as possible; and it was confidently asserted that mild steel was quite free from at least one defect often found even in the best brands of iron, namely

lamination or blistering. With care in manufacture the finished steel plate should certainly be free from this defect; but unfortunately this is not always the case, owing either to parsimony of the maker, or to carelessness of the workman; and on more than one occasion it has been discovered and pointed out by the writer. To guard against the occurrence of this and other defects, it is usual to insist upon the plates being examined in the boiler yard, and sometimes strips are required to be tested; but in the writer's opinion that is not the best course to follow in order to insure freedom from lamination and to obtain reliable plates. The proper place for examining and testing plates is at the steel works, where defects are more readily detected before the plates are sheared, and where test strips can be more readily prepared and tested, and unsuitable plates which have been rejected can be replaced quickly, thus obviating the annoyance of having to wait several days or weeks for replacing defective material rejected during inspection in the boiler yard.

Lamination in its worst form is often due to overlapping when rolling the slab into a plate; when so caused it may therefore be termed a mechanical defect. Lamination may also be due to the presence of a chemical ingredient, such as phosphorus, sulphur, slag, or carbonaceous matter; any of these tends to make up a layer of impure iron, for which the metallurgist is responsible.

Test Strips.—When the plates have been delivered to the boiler works, strips are sometimes cut off for testing purposes. Those taken from the manhole scrap generally give the best results, because any surface imperfection or lamination is least likely to be found in the centre of the plate; consequently such tests are most favourable to the steel maker. Strips cut from plate ends are far more likely to expose defects, such as blisters, overlapping, deficient thickness, uneven surfaces, and hardening due to the chilling effect of throwing plates hot from the rolls down upon the cold plate-floor. When free from mechanical defects, the test strips seldom fall short of the conditions stipulated. Curiously enough however there appear to be a greater number of defective plates delivered to boiler works when

the shipbuilding yards are busy, than when they are not so fully occupied. Whether this is due to indifference of the steel makers, or to ship plates getting mixed with boiler plates, does not concern the present subject; but at any rate the writer's experience is that at such times plates unable to bear the prescribed test are more likely to creep into the boiler shop.

When plates are ordered for the best boilers, it is generally agreed that their tensile strength shall be not less than 26 tons per square inch and not more than 30 tons, while the elongation must not be less than 20 per cent. in a length of 10 inches, the test strips being usually 2 inches wide. Occasionally a stated reduction of area is insisted upon; but in the writer's opinion this is decidedly wrong and sometimes misleading, because a strip not so homogeneous as desirable will often give a greater reduction of area at the fractured portion only, while a superior strip, in which there is a uniform flow under test, will give a good elongation, but not so great a reduction of area at the fractured part; if however the reduction of area were measured say in ten places in each of the two samples, and the average taken, it would be found that the latter strip would be much more reduced than the former.

In the bending test, the strip should be bent cold to a radius $1\frac{1}{2}$ times its thickness, until its ends are parallel with each other; and in the chill or temper test to a radius equal to twice its thickness. With plates from the best works there is no difficulty in getting these results.

Sizes of Plates.—As regards width, 3 feet to 3 ft. 6 ins. is found most reliable, and most convenient on account of the spacing of the mountings on the boiler crown. As to length, one plate to a ring is undoubtedly the best arrangement, because it allows all the longitudinal seams to be near the crown, and they are then always accessible, above water level, out of the way of corrosion, and clear of brickwork. But where there is not machinery suitable for handling such long plates, then two plates to a ring must be adopted, care being taken to keep the longitudinal seams clear of the seatings.

Form of Seam.—The butt joint with double butt-straps is without doubt the best and strongest; and it dispenses with the objectionable practice sometimes adopted of thinning the plate corners. In a butt joint the plates can be bent to a true circle; and when double butt-straps are used, the rivets are in double shear. In bending the plates for lap joints, there is only a slight deviation from the true circle; but in thick plates this occasionally leads to some slight damage in closing the joints at the corners where they have been thinned.

Thinning of Corners.—In most of the best boiler-works the corners of the plates are thinned by planing them down; but this in the writer's opinion is not the correct thing to do, unless the plates are made to a special shape. No doubt it obviates local heating and consequent internal strains in the plate; but is it certain that internal strains were not already in existence? From his own experience the writer thinks there is not much to fear in this direction, as he has tried several experiments to ascertain the effect of heating plates locally. In one case a piece of steel boiler-plate, shown in Fig. 9, Plate 109, was bulged out of shape in the middle, made hot at the bulge, hammered back to its original form, and planed into seven strips, which were then tested with the following results,

No. of Strip.	Tensile Strength. Tons per square inch.	Percentage of Elongation in 10 inches length.
1	27·7	23·7
2	27·4	20·1
3	27·5	20·0
4	28·1	23·7
5	27·8	25·0
6	28·4	23·7
7	27·4	26·2

showing that the local heating did not appear to have influenced the strength or ductility of the plate in the slightest degree. When thinned by machine, the material is cut away, Figs. 1 and 2, Plate 107, forming a short joggle which is not always easily closed. When thinned from the fire, Figs. 3 and 4, the whole of the material is retained, forming a longer joggle, which is easier to close, and the thin

corner will finish at the next rivet hole. If there is any legitimate ground for suspecting internal straining due to local heating, may it not be easily overcome by annealing the whole plate? In some cases indeed it is even stipulated that all the plates shall be annealed before use.

With butt joints the thin corners of plates are got rid of; and sometimes the same principle is carried even further, as shown in Figs. 5 and 6, Plate 108, by making the butt-strap end to butt against the edge of the next plate. This certainly makes a neat finish, but it is not so reliable as when the strap end is thinned and tucked under the edge of the next plate, as shown in Figs. 7 and 8. The thinning of the butt-strap ends is generally done from the fire, and then each strap is annealed in the furnace. In case of leakage, the joints thus thinned, shown in Figs. 3 and 7, are much easier dealt with and made good than the joints shown in Figs. 1 and 5.

Edges of Plates.—These are invariably planed in all the best works. The most suitable bevel or angle for free edges, other than butt edges, is considered by the writer to be 75°, as shown in Fig. 11, Plate 109. The angle is perhaps more important than would appear at first sight, because the edge should be planed to the angle most suitable for calking. When planed to the angle of 75°, then after fullering, which really means calking with a tool equal in thickness to the plate, the angle or bevel of the plate should be 80°, as shown in Fig. 12. Where this rule is adhered to and carried out systematically, bad work can readily be detected by merely glancing along the seam.

The proper angle for planing the plate edges when they are to butt together and form a close joint can be arrived at only by experiment. The smaller the diameter of the circle to which the plate is bent, and the greater the thickness of the plate, the sharper will be the angle required; while for larger diameters and thinner plates the edges will require to be planed more nearly square.

Bending of Plates.—Care should be taken to see that the sweep of the plate is carried to the very extremity in the bending rolls, so as

not to require the ends setting to the curve with hammers; there are plenty of bending rolls which allow of this being done when properly handled. Unfortunately it is not always done, and the plate is often hurried through the rolls, and is even bent to the full sweep at one operation, which is somewhat barbarous and should never be allowed.

Drilling.—The plates after bending pass on to the drilling machine. In order to hold them in position without a number of tack holes, inside and outside angle-rings are sometimes employed, with a number of set-screws in each, by which the plates are held in a circular form; but whether they are really drawn up metal to metal as tight as they should be is to the writer doubtful. His own idea of really good tight work is to drill first a number of small tack holes, say 5-8ths inch diameter and about 3 feet apart along the longitudinal and the circular joints alike, and to drill the joint holes with 1-8th inch draw, so that when bolting up in readiness for the drilling machine a drift can be inserted and the plates drawn up and bolted metal to metal, thus insuring good work; the 5-8ths inch holes can easily be drilled out finally to the proper size after the bolts have been taken out. By following this plan no extra time or labour is involved, but rather a saving of time is effected over other plans which are sometimes adopted. No doubt the use of the drift may be objected to; but in the writer's opinion it is in many cases essentially necessary to use it, if good work is required. In most boiler-works it is denied that any use is made of the drift; but where is there a works without it? and although no tool is more misused, yet, when properly used as above described, what tool will do so much good work? With the material of which the best boilers are now made there seems no reason why the judicious use of the drift should be at all feared. If a 2 inch strip will stand a $\frac{3}{4}$ inch hole drifting to $1\frac{1}{4}$ inch diameter without apparent distress, as so often shown, surely the drift may be trusted for drawing the work together. Not long ago, on the closing of a works from which the best class of boilers had been turned out, the tools sold were found to include no less than 10 cwts. of steel drifts that had been in use in the boiler shop. It is only in the hands

of inferior workmen, and with inferior material, that the drift is said to be worse than useless; but it only exposes that which should not exist, and in this connection therefore it has an unmerited bad name.

After drilling, the plates should be taken asunder, and the holes cleared of the burr left by the drills. With a proper tool this is not a difficult task; but it is important that it should be done, and in the writer's opinion the holes should even be slightly countersunk round the outer edge in order further to strengthen the riveting, especially where the rivets are in tension. It is when the plates are taken asunder that it can be discovered whether or not they have been drawn tightly together, metal to metal. If they have been put together as already suggested, no burr whatever will be seen between the plates, and no trace of slackness will be visible when they are again put together for riveting up.

Riveting.—The proper diameter of the rivets will be influenced by the thickness of plate through which they pass. In the pitch, not only strength but steam-tightness must be considered; occasionally therefore the adoption of the strongest pitch is precluded on account of steam-tightness, though the writer believes that wider and stronger pitches than at present used may be adopted without fear of leakage, particularly when steel rivets are employed, put in properly heated, and well closed into the holes. When rivets are thrown into the rivet furnace by the bagful, and then brought out by the shovelful, often thickly coated with oxide and slag, it is next to impossible to make good work. There seems no reason why the rivets should not be heated to a bright red heat, brought out singly, and each rivet passed through a fine spray of water, which would immediately chill any oxide or slag and cause it to shell off, without in any way affecting the rivet itself; and then a perfectly clean rivet would be put in a perfectly clean hole. The difference in the quality of the work will be readily seen by closing a dirty rivet and also a clean one, and then cutting them open through the centre, and polishing them; in the former case a film of oxide, sometimes 1-32nd inch thick, will be observed surrounding the rivet, while with the clean rivet the joint

will scarcely be discernible. The use of clean rivets may perhaps entail a little more labour and care, but it would prove worth all the trouble. It is desirable that all joint rivets which pass through an extra thickness of plate should be slightly larger in diameter than the seam rivets. For instance, in $\frac{1}{2}$ inch plates 13-16ths inch rivets are often used, which have to pass through 1 inch thickness of material and to draw two plates together; it seems therefore not unreasonable that three thicknesses of $\frac{1}{2}$ inch plate should have 7-8ths inch rivets, in order to make an equally good joint. No doubt an objection will be felt to reducing the overlap thereby; but in a joint the grip of the rivet is of more importance than the width of the overlap, while the gain would be about 15·9 per cent. in favour of the rivet section, against a loss of only about 3·8 per cent. in the overlap section.

Too much care cannot be exercised in seeing that the riveting is well done, both at the machine and by hand. If the rivets are not well closed in the hole, the previous attention to their size and cleanliness will be so much time wasted. To close a rivet well in its hole, it must be neither too hot, nor too slack in the hole, or else it will bend before it will thicken; and then it is impossible to fill the hole, however powerful the machine may be. The compression which acts on the rivet should not come upon it too suddenly, nor be of too short duration; but should rather be slow, so as not to leave the closed rivet at too high a temperature. Perhaps the best means of judging good sound riveting is to stand by when it is being done, and to notice how long the rivet remains hot. When a clean rivet is well closed in tight, it will go black immediately, showing that the colder metal round the hole has come in direct contact with the rivet and has abstracted the heat from it; while a slack or dirty rivet badly closed will remain hot for a considerable time. This will be seen at once by watching a good riveting machine, and then watching a set of hand riveters who seem to be giving more attention to the appearance of the rivet than to its usefulness and purpose. When engaged in piece-work on girders, it is astonishing how expeditiously the men can get through riveting, particularly when snap riveting. A few light blows from the hammer-panes are sufficient to form a rough

head, and then half a dozen blows on the snap finish the rivet while it is still at a bright red heat; but the body of the rivet has never thickened in the hole, simply because the light blows have not had any effect except just at the point where the snap head is formed. What is wanted is that the rivet should be well forced into the hole, either by a steady pressure from a machine, or by a succession of good blows fair on the end of the rivet; and the size and shape of head thus formed are only a secondary consideration. The end of all rivets should be perfectly flat, or they cannot well be driven home; for a bevel end will tend to divert the blow somewhat, and to bend the rivet itself, after which it can scarcely be expected to be made a good job. On this account it is not advisable to allow rivets to be used which have been too long and have been cut.

Flues.—Most of the points already considered with respect to thinning of corners, drilling of holes, and riveting, will apply equally to the construction of the two flue-tubes. The form of the flue will of course be circular, obtained by bending the plates to shape and welding the longitudinal seam, if it can be called a seam. Before bending, the edges must be prepared for the smith by planing to a suitable angle, either for lap or for butt welding. All plates 7-16ths inch thick and under are lap-welded, being bent and lapped over. Those over 7-16ths inch thick are butt-welded with a V piece let into the channel formed by the bevelled edges of the plate. When steel plates are used, they are planed at the edges, heated to a dull red for bending, and leave the rolls ready for the smith without further preparation.

Welding.—For welding, long fires are used, Figs. 20 and 21, Plate 111, with a pair of long parallel tuyeres, each containing a row of small blast-pipes, so that a full heat may be obtained along the whole length of the seam at once if required. When the rings of plates are welded under the steam hammer, five heats are sometimes found sufficient to weld a ring of plate 3 ft. 6 ins. wide. After welding, every ring should be carefully heated to a dull red along the weld, and be allowed to cool slowly, so as to

anneal the portions that have been hammered, and thus set free any internal strains set up in the welding.

Circular Joints.—For the circular joints which connect the several rings of plates forming the flue, the ordinary lap-jointed seam is far too weak for the high pressures now in use, and may therefore at once be discarded. The seam most generally adopted is the Adamson flanged joint, Figs. 16 and 17, Plate 110; but few even of the best makers seem to bestow as much care on it as was done by the originator himself. The radius of the flanging is generally less than desirable; and the liner ring of soft iron is not always of the proper shape. The liner should be of such a section before bending as will insure both faces of the ring being perfectly parallel after bending, so as to secure a good joint; and for this joint steel rivets are most advisable, because they are under a tensile strain alone. Among the strengthening seams that are in use, there is one known as the Bowling or Bolton hoop, Figs. 18 and 19, which perhaps for most purposes is a better seam than the Adamson flanged joint. The hoop should be put on hot, but should not be shrunk on the flue rings too tight, only tight enough to bring the hoop and rings together, metal to metal. If put on too tight, there is not only a difficulty in removing the hoop after drilling, but there is a probability that in the flue rings grooving or channelling will set in round the edges of the hoop, as shown in Figs. 18 and 19, after the boiler has been at work a short time. Like the shell, the rings forming the flues should be put together blank, or with a few tack or guide holes, and then drilled in position, all burrs being removed before the insertion of the rivets; and the same care should be exercised as in shell riveting.

The strength of flues, spacing of hoops &c., may generally be left with the maker, notwithstanding that he often follows custom rather than science; but since the prevailing custom of making flues with a strengthening hoop or flange to each seam gives an excess of strength, the usual practice allows an ample margin of safety. When however flues are occasionally made without strengthening hoops or flanges of any kind, owing to the want of suitable machinery for doing the best

work, a watchful eye is needed to supervise the construction not only of the flues but of the boiler as a whole.

Calking.—After the shell and flues have left the riveting machines, the next process is the calking of seams and joints, which deserves more attention than is occasionally bestowed upon it. In some shops a number of youths are employed, into whose hands the calking tools are put without any instructions as to their proper use. When this mistake is made, they are sure to do more harm than good, increasing the tendency to leakage, and rendering it almost impossible for another man to make the work good afterwards; and they may niche the plate in such a manner as to lead to a serious fracture. In the best shops a foreman riveter is employed to see that the calking is properly done, and to instruct those who have not previously been taught how to do it. All the tools used for calking should be ground to one uniform bevel, excepting only for special or corner work. When the plate edges are planed to the proper angle, it is easy for a practised eye to detect any irregular work. Calking never strengthens a seam, but often weakens or damages it; and before long the writer believes that seams will be made tight without calking by hand tools, and that this will be accomplished either mechanically by abrasion, such as that produced by the friction of the edge of a revolving disc pressed hard against the edge of the plate, or else by the use of paint or cement.

End Plates.—The shell and flues having been calked are ready for being put together, and for the ends to be marked off. In building up a shell or flue, say 30 feet long, however carefully done, there is always a tendency to creep, so as to be 1-16th or 1-8th of an inch longer or shorter than intended. This difference must therefore be made up in such a manner that the end plates shall be quite flat, without the slightest straining; for any strain existing in the boiler while at rest would certainly be increased when at work. Fortunately the best methods of connecting the end plates to the shell and flues are such as will accommodate any little difference there may be in length between shell and flues, the front end being

secured to an outside angle-ring, while the back end is flanged and fitted inside the shell. The flues having been run in, the front end plate is bolted up first, the back ends being left quite free. The back end plate is next put in place, and its flange is forced into the shell until the plate itself is close up to the flue ends; the holes in the flange are then marked with a centre punch, and the end so centred is taken down and drilled; after which all will go together, and can be bolted up and riveted without producing the slightest pull on any part, every portion being left in a state of rest.

As the end plates are flat, they require more care than any other part, in order to insure that they shall be of the proper thickness and efficiently stayed without rendering them too rigid. Expansion and contraction are ever in operation, and being uncontrollable must be accommodated; and how to do this has been a problem solved only by patient practice and observation. Were it not for these uncontrollable forces, it would be an easy matter to make end plates sufficiently strong not to require stays of any description, while even light end plates could be so stayed as to resist almost any pressure. As it is however, if the end plates of a boiler are not properly designed, their strength rapidly becomes weakness. They must be sufficiently pliant to yield to the varying expansion and contraction, without failing under steam pressure; and practice has shown that, in well constructed Lancashire boilers, end plates ½ inch to 9-16ths inch thick, when properly secured to the shell and flues and properly stayed, may be used with safety for pressures up to 100 lbs. per square inch. The manner of securing the front end plate to the shell is by an outside angle-ring, single or double riveted as the case may require; this arrangement admits of good sound work, is always accessible, looks well, and allows a breathing space at the sides of the flues to accommodate their expansion and contraction. A similar arrangement at the back end however, instead of the expensive flanged end, is not suitable, because the working conditions are entirely different. The breathing space at the back end, to accommodate the expansion and contraction of the flues, can be gained by reducing the diameter of each flue at the back end; and this practice is now generally followed, because it not only serves the

above purpose, but also enables a man inside the boiler to pass from the top side of the flues to the bottom without coming outside.

For the attachment of the flues to the end plates the angle-ring connection, shown in Fig. 13, Plate 109, is perhaps the oldest and still the best connection. Many devices have been tried to supersede it. When the end of the flue was flanged, as shown in Fig. 14, the root of the flange was found too weak to bear the strains arising from expansion and contraction, and it soon grooved and fractured. In order to strengthen the flange an additional plate was riveted on, as shown in Fig. 15, and was flanged with the flue plate, so that at the flange there were two thicknesses of material. At first sight this seems a neat and efficient piece of work; but on many occasions it has been found that the extra plate has not strengthened the flue plate, for the flange of the latter has been found to groove through, and the extra plate has simply concealed what it was intended to remedy. Although this plan is still sometimes followed, several works in which it had been adopted have returned to the old style, and use angle rings, which are not only strong but easily made and repaired. The connection of the flues to the end plates is the same at the back as at the front end.

Gusset Stays.—In regard to the position and mode of attachment of gussets, it will readily be admitted that the most uniform distribution of the load will be the best. The attachments to the shell will therefore be on the first and second rings of the shell alternately, with gusset plates between double angles, so that the rivets will be subject to a double shearing strain; and the angles should be arranged sufficiently close together to have a fair grip on the gusset plate. Owing to the flue attachments, and the expansion and contraction of the flues, it is not so easy a matter to distribute the load on the front end plate as would at first sight appear. The end plate is circular, and if it were not for the furnace openings all the gussets could radiate from the centre, as shown in Fig. 23, Plate 112; but it is found in practice that, in order to give a good distribution, the intermediate and outer gussets must radiate from points below the centre of the end plate, as shown in Fig. 24. This

arrangement evidently interferes with the free use of the ordinary angles, which invariably come to the boiler works as right angles. For the centre gusset radiating from the centre of the end plate, this is the correct form; but for those radiating from any other point, either the gusset plates themselves must be bent, as shown in Fig. 25, Plate 113, or else the angles must be altered to a suitable shape, as shown in Figs. 26 and 27. The bending of the plates is not advisable, seeing that a stay subject to a tensile strain should always be in a straight line. It is therefore important that the gusset plates should be straight, and that the angles should be altered to a suitable shape; the latter however is not an easy task, unless special machinery is used. As boilers of different diameters have the gussets radiating from different points, the angle of attachment will vary accordingly; and therefore the general custom is to knock the angle to a suitable bevel: a piece of work which is rarely satisfactory, but as it is in a position somewhat inaccessible it is often allowed to pass, while if it were more visible it would certainly be condemned. In bevelling these angles, the flange is indeed brought to the proper bevel; but the root of the angle is the same as at first, leaving an ugly section, and one not at all likely to have a good grip on the plate, as shown in Fig. 26. If this is to be altered, then the only way in which it can be done efficiently is either by blocking the angles or by re-rolling them, as shown in Fig. 27. Either process would no doubt entail a considerably greater first cost in plant; but as only a trifling expense in maintenance would be entailed, it appears to the writer that the improvement effected would be well worth the cost. It is of course advisable to have all gusset angles made of mild steel, so as not to be troubled with the reedy fractures so often found in angle iron and iron bars of similar section.

Longitudinal Bolt Stays.—When the end plates are well supported by gussets, longitudinal bolt stays are considered by the writer to be unnecessary. When the required support can be given to each end plate independently of the other, as it is by gussets, it is not advisable to tie the two end plates together by rigid tension bars, such as the longitudinal stays often are. If the shell were weak in a

longitudinal direction, then the support afforded by longitudinal bolt stays would be useful; but seeing that there is already an excess of strength in the shell longitudinally, the rigid bolts are worse than useless, inasmuch as they interfere not only with the accessibility of the interior, but also with the application of such fittings as the low-water safety-valve, and, what is most important, with the expansion and contraction of the flues and shell. Whenever these bolt stays are applied as a secondary support, they should be left slack enough to allow of the boiler attaining its maximum length by expansion before they are tight; and a good rule of thumb is to allow them when cold to sag downwards say 4 inches in a length of 30 feet. A loose hanger should be added to carry the weight of the stays, so that in case of transit the vibration shall not be likely to break them, as has many times been the case. Where there are no gussets, then longitudinal stays serve quite another purpose; and in many cases where they have been used in cylindrical boilers externally fired, they have served a good purpose when seam rents have occurred, in keeping the parts together; and although they have not prevented an explosion, they have reduced the extent of damage to narrower limits.

Seeing that all the rivets holding the front end plate, and many of those at the back end, are subject to a tensile strain, it is advisable that as many of them as possible should be riveted by machine, as hand-work does not compare favourably with good machine-work. Moreover countersinking the holes tends to strengthen the gusset-stay rivets.

Mounting Blocks or Stand-pipes.—These are now generally made of wrought-iron or mild steel, and by two different processes. In some cases they are made of angles of special section; in others they are made of ordinary plate cut to shape, flanged at both ends, and the top flange strengthened by having a plate or washer welded to it. The latter process appears preferable to the use of angles, because with angles it is not an easy matter to bring to shape a heavy section of material, such as is required, without the risk of making an unsound weld. Cast-steel stand-pipes are occasionally used; but the writer is not favourably impressed with these, having seen more than

one flange broken in bedding to the plate; moreover they are sometimes found to be so porous as to give much trouble in leakage. For the manhole mouthpiece probably the best fitting is the raised wrought-iron or mild-steel mouthpiece, double-riveted to the shell with rivets not too close in pitch, and with a doubling plate or compensating ring on the underside, as shown in Fig. 29, Plate 114. For size of opening it is found that 1 ft. 4½ ins. diameter is sufficiently large to admit any ordinary man to pass through, or any of the internal fittings used in the boiler. The manhole cover should also be of wrought-iron or mild steel, of not too heavy a section, say 1 inch thick, cambered 2 inches, and secured by sixteen bolts of 1 inch diameter. Such a manhole and cover have been tested by water pressure to 1,000 lbs. per square inch, without the slightest sign of distress. A light cover is more easily handled and jointed than a heavier one; and with a good number of bolts, the failure of any bolt, or the oversight of one not being screwed up tight, is of less importance than if only a dozen bolts were used of 1⅛ inch diameter, as is often the case at present.

Hydraulic Testing.—The final stage through which the boiler has to pass before leaving the maker's works is perhaps the most important, though not always so regarded. It has often been argued that the hydraulic test is of little use; in this view however the writer does not entirely agree, for although the Lancashire boiler is of such a form that the strength of every part may be ascertained with a fair amount of accuracy, still the hydraulic test has before now revealed defects which would otherwise have escaped notice. For instance the gussets may to outward appearance be good and firm, and yet may be fractured through the line of rivets; and the same might be the case with the bottom flange of the manhole. Many parts may be overlooked by the workman; and even the foreman cannot be expected to see every little detail. For testing a boiler the writer's recommendation is to proceed as follows: after making all joints good, connect a small steam-pipe, and turn steam into the boiler until there is a pressure of 3 or 4 lbs. per square inch, when any leakages at places not soundly calked or at loose rivets

can readily be found. These can then be chalked, and the steam blown out; the boiler being warm will soon get dry for the men to calk the leaky parts, which when dry are made good with about half the trouble entailed in calking a wet seam; in fact it is often impossible to calk a joint tight with a layer of water between the plates. After calking the visible leakages, every fitting intended to be used when in working trim should be placed in position, the boiler filled with cold water, and tested by slowly increasing the pressure until the working pressure is reached, when a general survey should be made of all parts of the shell and the inside of the flues; any leakages should be marked, the pressure released, and all weeps calked. Then should follow the final test, which may be arranged either with the fittings in position or with blank flanges on the stand-pipes; and the required pressure should be provided for by properly loading the safety-valves.

Here it has to be decided what is the proper test-pressure to apply. Testing the boiler to ascertain its fullest strength would mean testing it to destruction; and even before this extreme was reached the boiler would be seriously injured. There is therefore what seems a great difference of opinion among engineers as to the proper limit of test pressure, which has been variously given at from $1\frac{1}{2}$ times to twice the working pressure; but a closer consideration goes to show that there is not a great difference after all. For those who go in for a high test-pressure go in also for a high factor of safety; and those who advise a moderate test-pressure require only a moderate factor. For instance, a test of double the working pressure with a factor of 6 is about equivalent to a test of $1\frac{1}{2}$ times the working pressure with a factor of $4\frac{1}{2}$; in each case the test pressure amounts to one-third of the assumed bursting or collapsing pressure, and is a test that may safely be applied to most materials in engineering. The safest plan therefore appears to be to arrive at the bursting and collapsing pressures by careful calculation, and then to adopt a test pressure accordingly.

For the final test the boiler should be again filled with water, and all parts carefully gauged when at rest. The flues should be gauged both horizontally and vertically; and a good way of doing this is to

fix light battens across, the lighter the better, just tight enough to hold themselves in position at right angles to each other; when under test, any deviation from the original form will at once show itself by bending one batten and allowing the other to fall out; the amount of deflection can then be easily measured. The flat irregular surfaces of the end plates however are the most important, and should be carefully lined off, and light strings stretched tight across at say one inch distance from the plate; then by inserting a taper gauge or wedge, Fig. 10, Plate 109, between the string and the end plate, the slightest trace of yielding can be discovered, measured, and recorded. After seeing that all is in readiness, the pressure may be applied up to the working limit, at which all parts should be carefully gauged and noted. Should there be no yielding of importance, then the pressure may be increased up to the test limit by gradual increments of 10 lbs. or 15 lbs., a sharp watch being kept on all sides at each increment. When the ultimate limit is reached, a strict examination should be made of all parts, and accurate gaugings taken; these will generally occupy about half an hour, during which time the pump should not be used, in order that any fall of pressure may then be seen. If the pressure has been maintained within one or two pounds during this time, it may then be released, and gaugings again taken, and compared with the original gaugings taken before the pressure was applied, when any permanent set or deflection will be at once apparent. If so far satisfactory, the water may be run out; and a careful examination of all internal parts should be made, particularly of the gussets, and of all rivets that are in tension, as these do occasionally go wrong, especially in inferior work or with indifferent material.

If all parts have been found to stand the testing satisfactorily, the boiler may be pronounced quite equal to the requirements. If when forwarded to its destination it should happen to have been subjected to unusually rough treatment during transit, it is a good plan to have it placed over its seating ready for building in, and then to fill it with cold water, when any of the seams that may have been shaken can be re-calked; but there is no necessity for any further test.

Wherever the views set forth in the present paper are thoroughly carried out in practice, there can be no doubt that the trouble and cost involved in giving effect to them are judicious; and the user can rest assured that he has a boiler which will reflect credit on the maker, and if well kept will give entire satisfaction to himself.

Discussion.

Mr. Boswell exhibited some test pieces which he had brought to show the material that was met with in every-day practice in boiler works; they were not selected pieces, but had simply been taken at random as ordinary specimens. There were also shown two samples of riveting, planed down to the centre of the rivets, from which it could be seen how differently the rivets had been put in. One of the sections contained two machine-rivets, one of which had been closed with the rivet clean, after the scale had been shelled off by means of a cold-water spray; while the other had been closed with the rivet simply taken straight from the furnace. In the former it would be seen that there was almost perfect metallic contact between the rivet and the plates, whereas the other rivet showed a distinct layer of black oxide or slag on each side of the hole. The second section contained three rivets, one of which had been closed in clean by the riveting machine, and filled the hole well. The second rivet had been put in just as was so commonly done in girder work, by simply striking a few light blows on the end of the rivet with the hammer, and then snapping it as early as possible, so as to make a good snap head, but producing no tension, and not filling the hole. There had been some difficulty in keeping this rivet in position while planing, because it was so loose in the hole; and it could now be taken out readily. The third rivet had been put in by hand as would be done in high-class boiler making, in which the first care was to drive the rivet well into the hole, and a little less attention was then paid to the snapping; here it was seen that the hole was as well filled by the rivet as in machine riveting.

The paper was given not as representing the practice in any particular works, but as containing his own views of what should be done, as derived from an experience gained by passing through some of the principal boiler shops in the country. It did not therefore describe either what was being done or what was not being done in any particular instances; but presented his own views, which he had previously more or less advocated, as to what was best to be done or to be avoided in boiler construction. There were many points of importance to which full justice could not be done within the limits of the present paper. One of these was the gauging of the end plates under pressure, by stretching a string across them on a couple of distance blocks. It was customary then to measure the bulging by means of an ordinary rule, by which the deflection could be measured to about 1-64th of an inch; but by means of the simple light wedge-shaped gauge now exhibited, Fig 10, Plate 109, made to an angle of 15° or about 1 in 4, the measurement was read at any part to 1-200th of an inch with great accuracy; the smaller the angle, the more accurate would be the reading. The gauge was made of thin sheet steel, and afforded a simpler, quicker, and more correct way of making these measurements than by the use of the ordinary rule.

Professor Alexander B. W. Kennedy, Vice-President, said that, in common with others who were not boiler-makers but users of boilers, he should much like to learn something about the advantages and disadvantages of using boilers of the kind now described at pressures of from 150 lbs. to 200 lbs. per square inch. Though this particular point had not been touched upon in the present paper dealing with the construction of the boiler, it was a burning question with many engineers, and he thought might be fairly considered in the discussion, because the use of Lancashire boilers under such high pressures was no doubt intimately connected with the manner in which they were manufactured.

Mr. Druitt Halpin considered the range given in page 486 for the tensile strength of steel for boiler plates, namely from 26 to 30 tons per square inch, might with the material now available be raised a

(Mr. Druitt Halpin.)

little higher, say from 28 to 32 tons, allowing still the same range of 4 tons. This stronger material he found gave also rather more extension, namely 25 per cent. in a length of ten inches. The extension he thought should fairly be taken in connection with the breaking strain, and if the two were multiplied together their product formed a useful factor to which to refer the material tested; if the breaking strain was less and the elongation proportionally more, so long as their product remained pretty nearly the same, the material was a safe one. With the present material the factor he considered might be from 700 to 800, instead of only from 500 to 600 for the material dealt with in the paper. He agreed with the author that too much confidence should not be placed in the reduction of sectional area at the point of fracture, for he had never been able to see the use of knowing how much the material contracted in area at the place of rupture. Elongation he thought was a much more rational test.

With regard to the size of the steel boiler plates, he thought the author was right in assuming that plates could now be got long enough to go right round the boiler; at any rate this was the case with land boilers, up to 8 feet diameter. A boiler constructed of rings made each in one piece from a single plate had the great advantage that all the longitudinal seams could be kept away from the fire and clear of the brickwork on each side, the necessary strength being obtained by riveting the joints with double butt-straps, and without thinning the ends of the straps. In the latter respect however he had lately gone a little further by adopting a plan which he believed had first been brought out for marine boilers, and which he thought was an exceedingly good way of avoiding the necessity when using the double butt-straps of tucking the end of either strap under the edge of the next plate. The ends were generally tucked under in the manner shown in Figs. 7 and 8, Plate 108, which led to the straps being put into the fire for thinning their ends, and did not make so good a job. The plan followed in marine boilers was simply to put an additional patch-strap over the end of the butt-strap where it butted against the edge of the next plate, as shown in Figs. 5 and 6; the patch-strap was secured in place

by the final row of four rivets in the end of the butt-strap and by the four corresponding rivets in the circular seam. By that means all thinning of the butt-strap ends was got rid of. There was also another way of accomplishing the same object, which he had heard of lately; it was simpler, and he had heard it was efficient, but he had not tried it himself. It consisted in putting one additional rivet in the centre of width of the butt-strap at its very junction with the edge of the next plate, so as in that way to close what was of course the worst part of the joint, where the butt joint crossed the edge of the cylindrical joint.

With regard to riveting, he quite agreed that too much attention could not be given to any hand-riveting that had to be done in boiler work. There was now so much machine-riveting that it seemed as though hand-riveting were deteriorating, or at any rate wanted more looking after; for one serious trouble that was always met with in hand-riveting, especially in steel boilers, was when the rivets were snapped; there was then much difficulty in keeping the men from cutting the plates themselves, in order to make what they considered a neat finish.

For the flues he agreed that the Adamson flanged joint was generally made with too small a radius for the flanging: the larger the radius, the better would it be for the joint, which would thereby be allowed the elasticity that was wanted on account of the expansion and contraction. The Bowling hoop he thought was not so good as the Adamson flanged joint, because as a rule the hoop was made far too stiff, so that it had but little elasticity; in addition to this objection, it had two rows of rivets right in the fire, which was not the case with the Adamson flanged joint, where the whole of the rivets were away from the fire.

Calking was a process which, as done by hand, he himself never allowed in any boilers that he had to do with. If a boiler could not be got tight with bare fullering only, the riveting must be so bad that it had better be left alone, especially where all the plate edges had been planed and all the holes drilled, as they should be. A pneumatic tool however was exhibited, which had recently come into use and he thought was a good contrivance for calking by machine.

(Mr. Druitt Halpin.)

It was worked by compressed air, and gave a very rapid succession of blows of uniform force; he understood it did good work in careful hands, and cheaper than hand calking, but he had not seen it in operation.

Gusset stays were certainly difficult to deal with, especially in regard to the angle-irons attaching them to the barrel of the boiler, as shown in Figs. 25 to 27, Plate 113. In the end elevation in Fig. 24, Plate 112, the gusset stays were shown well apart from one another and from the flues, which was a great advantage in giving the boiler end-plates room for breathing; and he hoped the author would also show what he considered the best practice in the longitudinal direction as well, which would render the construction of these stays more completely clear. [See Fig. 22, Plate 111, added accordingly.]

With regard to the mountings, he certainly did not like these to be made of cast steel; it was too porous, and was now made far too brittle. In some steel castings that he had known of, it had been found that when tested for tensile strength they barely stood one ton per square inch.

Mr. William Schönheyder agreed in the great desirability of having all the rivets slightly chilled on the outside by a water spray, so as to remove all the scale before putting them into their holes; it was interesting to see the close joint thus obtained in the specimens now exhibited. If it was desirable to treat the rivets in this way, it was equally desirable to produce the same effect in the plates: not of course by heating them and cooling them with water, but by removing the scale in some other way. This was sometimes done by immersing the plate in acid, thereby removing all the scale from it. That made a much closer joint, and enabled calking to be done away with, because the plate had then a clean surface all through the joint, instead of being here and there covered with scale; unless the scale were removed, the joint was not made with a perfectly smooth surface, which was quite as important in the plates as in the rivets.

The undue stiffness given to the Adamson flanged joint, by flanging the plates to too small a radius, had been properly commented upon; and the Bowling hoop he thought was rendered

quite useless by being made far too stiff, as shown in Fig. 18, Plate 110. In the front view of the boiler, Fig. 24, Plate 112, the innermost rivets of the gusset stays were rightly shown at a considerable distance from the flues; and he should be glad to know whether that drawing was intended to represent what was the usual practice. A distance of about 9 inches from the centre line of the circle of rivets round the flue to the nearest rivets of the gusset stays he believed was considered necessary: the more the better. But in making boilers of this description he thought it might be advantageous to go a step further; and instead of a breathing space of 9 inches, the whole width of the end-plate might be given as a breathing space, by simply strengthening the flat end-plate with girders instead of putting in gusset stays. This was a plan he had adopted in several cases, where certainly the pressures were not high; and it seemed to him that it gave the whole end-plate a much freer breathing space than when gusset stays were used. When these were so dispensed with, the longitudinal strain would of course come upon the angle-iron which fastened the end-plate to the shell; it did not follow however that this would give rise to any difficulty at all. Longitudinal bolt-stays he thought were properly condemned in the paper, at least to a certain extent and for most purposes. It was impracticable to arrange them in such a manner that they should always do their duty. If the gusset stays were carried too near the flues, they gave too much stiffness; and similarly the longitudinal bolts would also give too much stiffness.

For strengthening the boiler shell at the manhole, he considered that the addition of the doubling plate or compensating ring inside the boiler, as shown in Fig. 29, Plate 114, was practically useless, unless the plate was almost covered all over with rivets uniting it to the shell of the boiler. Otherwise no strain in the circumferential direction could be brought on the doubling plate until it was drawn straight or nearly straight, as would be best seen in a cross section of the boiler. If the boiler shell-plate outside was steam-tight, and the doubling plate inside having also the same curvature was riveted to the shell along the bottom edge only, by the single longitudinal row of rivets shown in Fig. 29, it was impossible for any circumferential

(Mr. William Schönheyder.)

stress to come upon the inner plate until it was drawn straight. If it were intended really to strengthen the boiler at the manhole, it should be riveted steam-tight to the shell, and in addition a few leakage holes should be made in the shell itself. Then the inside plate, being pressed outwards against the shell by the internal steam pressure, would act in the manner wished; but certainly not, when merely fixed as shown in Fig. 29.

Although the paper did not treat upon the design of Lancashire boilers, but upon details of their construction, there was one point in the design of such boilers which was important for enabling their construction to be carried out properly, namely the arrangement of the circumferential seams so that those in the shell should be quite clear of those in the flues. This was important not only in the original construction, but more especially with regard to subsequent repairs. It would therefore be a great benefit if the author would give a longitudinal section of the boiler, showing various details of that kind, which were sometimes overlooked with great disadvantage to the future use of the boiler. [See Fig. 28, Plate 113, added accordingly.]

Mr. William H. White, Member of Council, thought that the subject of test pressures, though referred to in the paper, had scarcely been adequately treated in the light of present experience with other kinds of boilers. In the Admiralty practice for marine boilers, as was known, the principle of making the test pressure a multiple of the working pressure had been departed from, and it was considered more satisfactory to have a certain constant margin beyond the working pressure: that is to say, the test pressure was the working pressure plus a constant. This practice had led to a sensible reduction in the weight of marine boilers and in the thickness of their shells. There had now been some years' experience of working on these lines, and there had been no trouble whatever. The internal parts of the boilers had not been reduced below what was considered the best marine practice; but in the shell plating on the new plan there was a sensible saving in weight, with no loss of efficiency. It might be within the knowledge of many present that Mr. John Scott

of Greenock, having made an experimental boiler shell in accordance with the Admiralty practice, had not succeeded in testing it to destruction by hydraulic pressure, because it declined to be destroyed, the leakage exceeding the pumping power before the bursting pressure could be reached; he had tested it most thoroughly, and had given an account of the testing in the Transactions of the Institution of Naval Architects (1889, page 285). So far as his own knowledge went, he thought the statement in the paper (page 500) was not quite correct, that those who advocated a high test-pressure advocated also a high factor of safety.

Mr. John A. F. Aspinall mentioned, with regard to the thinning of the corners of the plates and afterwards annealing them, that in locomotive boilers, wherever a plate had to have its corners thinned, it was always the practice to anneal it after it had been brought to its proper shape. For instance the front plate of a fire-box, or any other plate which had been flanged and had then had its corners thinned, was invariably annealed after the whole of the work had been completed upon it in the way of flanging, drilling, and thinning down the corners, in order that the annealing might leave the metal in a perfectly quiescent state, free from all internal strains. Where plates had not been thoroughly annealed after the corners had been thinned, but without reheating had merely been placed while hot in saw-dust or ashes, he had known them break in the boilers after perhaps twelve months' work. This showed that the thinning down and partial heating set up internal strains which were difficult to get rid of otherwise than by thorough annealing.

With respect to calking, or more properly fullering, probably some of the members who visited the Horwich locomotive works at the recent summer meeting had seen there one of the pneumatic calking tools driven by compressed air, like those now exhibited. He had lately been told by a prominent boiler-maker in Lancashire that he had used these tools to a considerable extent, and that an important saving of labour was the result. So far as his own experience at Horwich was concerned, he had merely used one thus far for experimental purposes; it had done good work, and so far as he could see it was a tool of great promise.

(Mr. John A. F. Aspinall.)

With regard to removing the burr from the rivet-holes after drilling (page 490), he had tried an experiment on this point some years ago* with riveted joints, and had found that by taking the burr off to the slightest possible extent, not more than a mere scraping of the edge of the holes, a material increase in the strength of the joint was obtained in the testing machine. The rivets did not shear anything like so soon, because the sharp edge was taken away; and in joints proportioned with only a narrow margin of safety he had no doubt it would be a great advantage slightly to scrape off all the edges of the rivet-holes, not to the extent of countersinking, but merely taking off the very edges.

Mr. Henry D. Marshall, Member of Council, said his own practice was principally with locomotive boilers, and he would not attempt therefore to go into the details of Lancashire boilers; broadly however he agreed with the remarks that had been made by previous speakers.

Mr. Ralph H. Tweddell said that, although not himself a boiler-maker, he had been consulted in reference to boiler-making of all kinds—stationary, marine, and locomotive—for nearly thirty years. The present paper therefore dealt with a subject full of interest to him; and he considered it was eminently one of those practical papers that were calculated to provoke discussion; and after all it was discussion he thought which was wanted, and for which a paper on any subject should really be only the ground-work.

Calking was a process which he considered ought to be altogether eliminated from the boiler shop; it might as well be attempted to make a piston steam-tight by calking, as a boiler seam. Calking as done in the old-fashioned way was simply a means by which, after the plates had been well put together by riveting, a bad workman tried to undo the work that had already been done, and to make occasion for another job later on. That object was effectively secured by using a sharp calking tool, inserted first of all

* Transactions of the Institution of Civil Engineers of Ireland, vol. xvi, 1885, page 227.

with great care at the very nick of the joint, and acting upon as small an area as possible, and struck as heavy a blow as possible with a hammer. Then the fullering tool came afterwards, to conceal the mischief done by the calking chisel. It would be remembered that at a former meeting Mr. Webb had described (Proceedings 1881 page 260) how at Crewe he did not calk boilers at all, but fullered them with a tool having a half-round edge, which when hammered into the plate-edge had of course no tendency to lift the plate up and thereby open the joint, but simply forced part of the metal down if required against the plate beneath, thereby making the joint tighter. That was what he considered quite a fair thing to do; and that was all that ought ever to be required in a boiler in the way of calking. If anything more was required, then either the riveting was bad, or the plating was bad, or both; and he thought it was certain that boilers should be made perfectly steam-tight without calking. The pneumatic calking tool now exhibited was no doubt an ingenious instrument, and with a properly shaped end, such as he had mentioned as being used at Crewe, it no doubt did the work well. In the principle there was nothing novel. Fifteen or sixteen years ago he had been concerned in calking a boiler with a rock drill on the same principle, and the work was done successfully; and the only objection was the great noise that was made in doing it. The machine he believed was a fair substitute for hand-labour for fullering up the edges of the plates. A similar machine he had also seen at work upon marble two or three years ago, cutting out graven images somewhere near Westminster Bridge.

In connection with the drilling of the rivet holes, he admired the candour of the author in regard to the use of the drift (page 489). There could be no doubt that the drift was in daily use; and those who said it was not used could not have spent much time in the boiler yard, where it was found to be a valuable tool. At the present time the drilling of the rivet holes was so well established that it seemed almost treasonable to make any remarks against it. Nevertheless he had himself still a hankering after the good old punching machine; and if, according to the most approved practice, the punching machine was never used in boiler-making, what were all the punching machines

(Mr. Ralph H. Tweddell.)

doing that were still seen in boiler shops? Were they there for ornament? or as dreadful examples of what was to be totally avoided? Perhaps the author would be able to say what punching machines really did in boiler works. The members had often listened to the remarks of the late Sir William Siemens upon the punching of steel plates, and the advantages of the process in many respects. That was of course many years ago, when the properties of steel were not so well known as at present; but it was certain that punching did strengthen the plates between the holes punched, and that any injury due to the punching was limited to a very small annular area around the hole, and this could be rimered out at a nominal cost. It was also certain that punching the plate was a cheap and effective test of its quality, and a test which any one could see. If two or three holes were still done by punching, what was the good of drilling the rest? The strength of a chain was that of its weakest link. Indeed there was a greater danger in punching only two or three holes and drilling all the rest, because with only so few holes punched it was not thought worth while to anneal the whole plate; whereas if all the holes were punched, the plate would be annealed throughout as a matter of course. Although for many reasons he could not now advocate a return to punching, he nevertheless thought there was too much made of drilling. The fact was that in the old punching machines the punch came down sharp on the plate, much like a projectile from a gun, and it produced a similar effect on the plate. But it had been proved by experience that when the punch was driven slowly and steadily down, as was done by hydraulic pressure, the effect on the plate was not the same as when the hole was punched by a geared machine; there could be no question about the difference. Of course drilling was desirable in many ways; but he questioned whether it was more economical or better than careful punching.

In the absence of any allusion in the paper to the relative advantage of machine or hand-riveting, he thought it desirable to point out the fact that in one of the societies for inspecting marine boilers, the Bureau Veritas, a factor of safety of 5·5 was allowed for hydraulic riveted work, as against only 5·0 when the riveting was not done by hydraulic power.

Little allusion had been made to flanging machines: and indeed he imagined that the boiler described in the paper and illustrated in the drawings was built without the use of a flanging machine, for there seemed to be no necessity for one to be used in its construction. It appeared to him that the flanging machine was a valuable addition to a boiler yard. It enabled a great deal of angle-iron work to be done away with; and this was particularly advantageous in regard to the boiler-end and furnace-mouth joints. Such a press would also be utilized for the manufacture of manhole doors for marine boilers, in which the pressures were higher, and the risks were much greater on account of the larger diameter of the boilers and the greater thickness of the plates and the conditions under which the boilers worked. For those boilers the manholes were pressed to a suitable form in a hydraulic press, and were then corrugated; and thus made would stand a test of 2,000 lbs. per square inch without deformation, instead of only the 1,000 lbs. per square inch mentioned in the paper (page 499).

With regard to the attachment of the flues to the end-plates, he thought the entire difficulty referred to in page 496 in connection with the joints shown in Figs. 13, 14, and 15, Plate 109, would be overcome by carrying the flue straight through the front plate, and riveting the angle-iron outside round the end of the flue projecting in front. Against that plan he knew there had been a prejudice among marine engineers for many years; but at the present time he believed fifty per cent. of the furnaces for marine boilers were carried out in that way, without the slightest trouble having been experienced. The whole of the rivets were visible outside; and if riveted up with a sufficient pressure and a suitable machine the joint was absolutely tight. The same remark would apply to the other end of the boiler, if the back end-plate was itself flanged outwards all round the projecting end of the flue; and this was also done where there was the necessary flanging machinery to ensure the shape of the plates being true, and sufficient power in the riveting machinery to ensure the plates being brought close together. Against this construction also he knew there had been a prejudice, which usually found expression in the remark that there was here no calking edge at the end of the flue.

(Mr. Ralph H. Tweddell.)

It was the old story however; a calking edge was not wanted if the work was well done. Makers who had constructed boiler furnaces on this plan would confirm the statement that it obviated all buckling and strain, and the other difficulties referred to in the paper.

With regard to the testing of the boiler, the option had been given in the paper (page 500) of testing finally either with the fittings in position or with blank flanges only on the mountings. In his own opinion however there should be no option; for it seemed obvious that, where the fittings were so numerous, it must be better to insist upon their being all on the boiler while it was under test, instead of being put on afterwards. He should therefore like to know the reason for the option being allowed in the paper, because the author had evidently considered the alternative.

The value of the paper he suggested would be increased if a reference were added to the previous papers read on cognate subjects. This might not be required for those who had the Proceedings for a number of years past, and could readily refer to such papers as those of Mr. Greig, Mr. Marten, Mr. Fletcher, and others relating to experiments with steel plates, and so on; but it would be of great value he thought to more recent members if references to such papers were added to the present paper.

Mr. William Jenkinson said his experience of leakages in boilers at high pressures was that there were more leakages from flanged joints than from any other part of the boiler. In boiler shops he had noticed that, before the flanged joints were calked, a penknife, and sometimes a much thicker knife-blade, could be put in all the way round the flanged seam, between the flange and liner. That was no doubt owing in a great measure to the joints having been riveted too hastily, without the pressure of the riveting die being kept on the rivet head long enough after closing it. With machine riveting indeed it was a common thing in some boiler shops to see half a dozen newly closed rivets still hot at one time. Of course when the closing pressure of 30 or 40 tons on each rivet was taken off so soon, the seams were sure to spring open before the rivets had become cold enough to hold them tight together. Another faulty

procedure which he had noticed was that when boiler plates were flanged they were in many cases left to cool upon the flat block with the flange free, and then of course the flange slightly recovered itself in cooling, and was not quite at right angles to the flat portion of the plate. Consequently when the work came to be put together, the flange was found to be gaping open to the extent sometimes of a quarter of an inch difference between the edge and the root of the flange, which necessarily produced a serious strain upon the joint when riveted up. The width of the flanges was also a matter of importance, for it was almost impossible to make good work with the narrow flanges sometimes adopted. Where the width of the flange was little more than $2\frac{3}{4}$ or $2\frac{7}{8}$ inch, a tight joint was almost out of the question, however powerful the riveting machine might be, and however careful the men working it. Another important point in flanges was that the radius of the curve to which they were bent over should be large enough to prevent injury to the metal at the root of the flange. The Adamson flanged seam was in his opinion the best for flues of Lancashire boilers, but great care was required in all its details during construction. The strengthening or doubling plate inside the manhole he supposed was not expected to be used in high-class work in exactly the way shown in Fig. 29, Plate 114, even if that were the best means of stiffening the shell round the aperture and compensating for the removal of the portion of plate cut out; the single row of rivets there shown could hardly be accepted in a high-pressure boiler as equivalent to the strength of the seams.

Mr. Edward B. Marten, Member of Council, said that, while the design and working of the Lancashire boiler had been amply discussed on previous occasions, the scope of the present paper comprised the modern practice in making the boiler, the details of its construction, and especially the tools that were used by the best makers. It gave not merely the individual opinion of the author, but also the result of his observations during his extensive acquaintance with some of the best boiler shops in Lancashire. This was indeed most useful material as a subject of discussion; and if

(Mr. Edward B. Marten.)

the information given had not quite fallen in with the views of other boiler makers present, they would doubtless have pointed out where their practice differed from what had been described in the paper. No doubt the Lancashire boiler was the most popular for many works, and was made more largely than any other kind. Its manufacture had also much improved in quality, owing a great deal to the use of improved tools. In some shops no hand-labour was used anywhere, the whole of the work being done by machinery. Even since the paper had been announced for the spring meeting six months ago, he had met with two more tools which would save any need of hand-labour. One was for drilling the rivet holes in the circular seams of the flues while standing upright, so that they could be turned round, accurately marked out by the tool itself, taken to pieces, and put together again at exactly the same rivet holes, and finally riveted up by machine: instead of dealing with them in the horizontal position, in which their own weight displaced them to an extent sufficient to interfere with good work. The other tool, which was all ready to work, though he had not seen it in operation, was for the purpose of planing the circular edges of the circumferential plates after they had been bent. The usual practice was to bend them after planing, and then they had to be handled a good deal, with the result that the planed ends or circular edges especially were much injured. By using this machine the cylindrical ring never had to touch the ground after its ends had been planed; and not only were the circumferential edges planed in their places, but also the longitudinal edges likewise. The latter were accordingly planed to the proper bevel for enabling them to butt together true and form a close joint when riveted up.

The present Lancashire boiler was no doubt being made in such a way as to be much better than it had ever been before. Having himself studied boilers rather from their failure than from their manufacture, he might mention that part of the statistics which he had recorded was what proportion of each kind of boiler had failed, and to which of three causes the failure had been due, whether to bad construction or to bad inspection or to bad working. Taking the whole number of explosions of boilers of which he had compiled the records

during the last twenty-nine years at about 1,467, it so happened that about 468 were of Lancashire boilers, of which about one-third, or 32 per cent., had failed from the first cause, namely bad construction. If however the failures from this cause were divided into two periods, it would be found that a great improvement in construction had set in about 1874. Before that date those Lancashire boilers that had failed from bad construction had been about 40 per cent.; whereas since that time only about 22 per cent. had failed from the same cause, showing that there was a decided improvement in their construction, by which he meant in their actual manufacture. Taking last year by itself, the percentage was still lower: only two out of fourteen had failed in any way through bad construction, that is only 14 per cent. More especially to those who could not go through the boiler shops of Lancashire was the paper interesting as a description of what was really done there. To his own knowledge it was a description of what was being done in some of the best shops in South Staffordshire, where great improvements had been introduced of late years, and where the two new tools that he had referred to as producing better work had been set up.

Referring to the test illustrated in Fig. 9, Plate 109, he had expected that steel makers or steel users would have something to say on that mode of treatment. No doubt the practice was not to thin down the corners of plates in the fire, but to cut the metal away; and it seemed to him that the latter method was almost essential, because steel plates behaved so curiously if one part of a plate was heated up while the rest was not. From the description given of the experiments illustrated by Fig. 9, it seemed to be implied that the steel plate was not so much injured by local heating as engineers had been accustomed to believe; but this important point was still left in doubt. It had not been mentioned that a great many large plates were bent horizontally, that is by horizontal rollers. The horizontal mode made the weight of the plate come so awkwardly in the bending, especially towards the finish, that many makers now bent the plates upright, standing on their circular edges, and thus brought them to a truer circle.

(Mr. Edward B. Marten.)

One other point, which had been slightly alluded to (page 484), was that makers who had the best tools could make the best boilers without increasing the cost of the work. This had often surprised himself, but it was no doubt quite true; and it evidently showed that a boiler made by machinery could be produced at a lower price than one made by hand. Such a result was what was wanted by all users of boilers, if the work done by machinery was as good as that produced by hand-labour.

Mr. J. F. L. Crosland observed that no reference was made in the paper to any higher working pressure for Lancashire boilers than 100 lbs. per square inch. When consulted twenty-three years ago as to the design of a boiler for 150 lbs. pressure to work a triple-expansion engine in a flax mill, he had found that nothing could be done for such a pressure with the class of large Lancashire boilers then made of iron with punched holes. He had therefore been compelled to design a boiler of smaller dimensions, not more than 4 feet diameter, of which some 120 to 150 had been made from 1868 to 1870, and many were still at work. Some of them had been worked at from 150 to 175 lbs. pressure with triple-expansion engines. Since that time attempts had been made gradually to increase the pressure in Lancashire boilers from about 70 lbs., which was then the maximum, up to 100, and afterwards to 150 and 160, until now in Lancashire these boilers were being made for 200 lbs. pressure. Twelve such boilers were at the present time being made under his own supervision for the purpose of using quadruple expansion, which was now being introduced into mills in Lancashire. The increase in pressure had practically been due entirely to the excellent material supplied by some of the steel makers. Great improvements had also been made in the joints; and while butt joints with double butt-straps and double riveting were the best and the strongest that were referred to in the paper, it was generally admitted that treble-riveted joints were still stronger, and these were now being used for the boilers to carry 200 lbs. pressure. Although 3 to $3\frac{1}{2}$ feet had been given (page 486) as the best width for the plates, it would be better if the whole boiler could be made in one single

plate; at any rate he thought the wider the plates were, the better. Steel makers he believed could now supply plates more than 3½ feet wide, and boiler makers would be glad to work them. The weight of a plate was not now of so much importance as formerly, when there were not the means of dealing with such large and heavy plates as were now used. At the present time boiler practice was being brought up to something more of an equality with engine practice. From what he had heard he imagined there would not be much difficulty in getting plates 4½ feet wide. The fewer joints in a boiler, the better; and he looked forwards to the possibility of dispensing with the longitudinal joints altogether, by the production of weldless rings rolled from the ingot into cylindrical lengths of the required diameter and thickness. Boilers so made would be perfectly safe with 200 lbs. pressure per square inch, or even more. As for the flues, if they were strengthened by anti-collapsing rings placed near enough together, they could equally withstand the same high pressure. The test pressure was a matter on which he entirely disagreed with the paper, as he considered it was not necessary it should always be a certain multiple of the working pressure. His own practice was simply to fix a satisfactory excess of pressure, say 80 lbs. or 100 lbs. excess for boilers intended to work at over 100 lbs.; so that for working at 150 lbs. the boiler would be tested to 250 lbs. per square inch.

Mr. Jeremiah Head, Past-President, said it was evident that the author had taken a great deal of pains in the preparation of this paper, and had candidly given the results of his own experience and observation, which naturally might not be the same in all respects as those of other members. With regard to the size of plates for boilers, those who were present at the Sheffield meeting last year would remember that they had then actually seen at the Parkgate Works four large steel plates, of which one was 50 feet by 5½ feet and ⅝ inch thick, another was 20½ feet by 11½ feet and ⅝ inch thick, the third plate was 11⅞ feet diameter and 1 inch thick, and the fourth was 11½ feet diameter and ⅝ inch thick. There was therefore no difficulty whatever in making large plates with modern machinery. But it

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must not be forgotten that it was not possible to make very broad plates of small thickness. The minimum thickness above mentioned was $\frac{5}{8}$ inch; and when it was desired to reduce this to $\frac{1}{2}$ inch and $\frac{7}{16}$ inch, the area and especially the width must be proportionately reduced. For in making broad thin plates, the rolls always sprung, and the plates were therefore thicker along the middle of their width than along their edges: so that some difficulties were met with which might not be seen at first sight. At the outset of the paper it was stated that the steel plates considered most suitable for the construction of Lancashire boilers were made by the Siemens-Martin open-hearth process, meaning no doubt the acid process. But there were some steel works which were now turning out steel plates made by the Siemens-Martin basic process; and it would therefore be interesting if any engineers who had had experience of the latter plates would state whether all the requisite tests could be got with the basic plates, in the same way that could be done with those made by the Siemens-Martin acid process. In talking about steel plates it must not be forgotten that the great bulk of the boiler plates and ship plates supplied at the present time were made from Spanish ore; so that this country was largely dependent on a foreign country for the material from which these valuable manufactures were produced. Any process therefore that would enable native material to be used would be of great advantage. It was true that a small supply of plates was produced from the hematite ore of Cumberland; but five-sixths of the pig iron produced in this country was made from the less pure native ore, which it would be of so great benefit to utilise for the manufacture of steel.

In page 485 the desirability had been urged of doing at the steel works all the testing of the steel material. No doubt that plan would save the boiler-maker a great deal of trouble; but it ought not to be exclusively relied upon. Plates, angles, and other material that came into the user's works, should be carefully examined by him before any labour was put upon them. For instance, lamination had been mentioned in page 485 as appearing in steel plates, when, considering the way in which they were made by fusion, it would

scarcely be expected to be possible that there could be anything of the sort; and the reasons assigned for its occurrence were, overlapping in rolling, and the presence of certain impurities in the metal. No mention however had been made of the most frequent reason of all for that lamination in steel plates, which was the occurrence of blow-holes in the ingot. When the ingot came to be rolled, these blow-holes, however small, became flattened, and afterwards gradually enlarged in the successive rollings; and as they were never welded up afterwards, because there was never heat enough to weld them after the ingot had once become set, they appeared in the plates as laminations. Frequently they did not come out to the edge or surface of the plates at all, and therefore could not be seen until after some work had been put upon the plates by the boiler-maker. Sometimes the shearing of the plates would cut through one of these laminated places, and it could then be seen. That was one reason why there ought to be a careful examination after shearing, and also when any other work had been done upon the plates in the boiler-maker's yard. In the steel-maker's works the men were almost all on piece-work, and their object was to get the work passed and sent out as quickly as possible; they were therefore not likely to take the pains that the boiler-maker himself would take, or ought to take, in examining the material before putting upon it work which would afterwards have to be thrown away if there was any defect in the plate. He should like to learn from the author whether the difficulty still prevailed, of which so much had been heard some years ago from the late Mr. Daniel Adamson, arising from the alleged danger of manipulating steel at what he called colour heat or black heat. There were some steels he knew, having tested them himself, which were exceedingly brittle if meddled with at all at that heat; while others did not seem to present the same difficulty. Any information derived from experience or observation of this point would be highly useful. The experiment illustrated by Fig. 9, Plate 109, did not appear to him to be at all conclusive. The middle part of the plate he understood had been dished out, and then made hot and flattened back again under the hammer; after which the plate had been cut up into the seven strips shown, and these had been tested in a tensile testing machine

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to see whether their tensile strength had been at all interfered with. He could readily conceive that it would not be found to have been interfered with, because any internal strains would soon settle themselves when the strips were subjected to testing, so that they would not be discovered. But the real danger and difficulty would arise if the plate were treated as had been described, and then left as it was, in a state of unequal tension, without being cut up into strips. That was where the danger would lie, unless the plate was subsequently annealed.

Another matter on which he should like to have further information was the bending of the plates after the rivet holes for the longitudinal joints had been drilled in them. The difficulty to be anticipated was that, if a longitudinal row of holes was made beforehand through a plate and the plate was then passed through the bending rolls, the bend at that part of the plate would all run into the line of the holes: just as, in trying to bend to a regular curve a sheet of perforated postage-stamps, it was found that the bend all ran into the lines of perforation, producing a polygonal shape instead of a curve. The line of rivet holes being the weakest place, the uniform bending strain put upon the plate would always bend it there more than anywhere else. Therefore it was exceedingly difficult to get a true curve even in the bending rolls, if rows of holes had been made in the plate beforehand. This was a reason for avoiding as far as possible making any holes in the plates before bending, and for drilling all holes in them after they had been bent.

There was still a great deal of difference of opinion as to steel rivets and iron rivets. The general opinion of engineers he thought was not as yet at all settled on this point; and he should like to hear something on the subject, as to whether steel rivets could be relied upon in all cases, or whether they could not.

Referring to the factor of safety in testing boilers, a test amounting to as much as one-third of the ultimate strength was spoken of in page 500 as one that might safely be applied to most materials in engineering. There were hardly any engineers however, he thought, who would like to test any material or structure that they had to do with up to so great an extent as one-third of what would break it.

Mr. John Phillips noticed that the statement in page 487, that in a butt joint the plates could be bent to a true circle, seemed to imply that the bending in the rolls could be carried to the very ends of the plates; and he enquired what rolls there were that would bend a plate up to the very end in a true curve. All the bending rolls that he knew of left the ends of the plate flat or straight, through a length nearly equal to that of the tangent line touching two adjacent rolls.

Mr. Boswell was rather surprised that what seemed to him to be the principal innovations contained in the paper had scarcely been touched upon in the discussion, namely:—larger joint rivets; passing the hot rivet through a spray of water to chill and shell off the oxide and slag; drawing the plates together with tack holes and drifts before drilling; re-rolling or blocking the gusset angles to a proper angle; and spreading out in a fan-tail shape the thinned corners of the plates, so as to finish with the thin edge across the centre of the next rivet-hole.

As the object of the paper was to give a few practical details in regard to the construction of Lancashire boilers, no comparison had been attempted with other boilers in regard either to pressure or to other features. Lancashire boilers for 200 lbs. pressure had already been made and were working; and since the paper was written, others of larger size had been ordered and were being built for working at the same pressure; and it was with a knowledge of these facts that the mention of any particular pressure had been studiously avoided in the paper. It should however be borne in mind that it was not everybody who wanted such a high pressure; to many it would be worse than useless. For instance in bleaching, dyeing, and general manufacturing works using raw steam, there was no use for such a pressure. In spinning mills no doubt it was useful and economical for engines working at a high pressure and using steam expansively; but that was for engines only, while the general working pressure in 90 per cent. of the mill and works boilers in Lancashire and Yorkshire was below 100 lbs., not because engines and boilers could not be got for a higher pressure, but rather because

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they would not be profitable. The higher the pressure, the greater he considered was the need for following the indications he had offered in the paper.

As regarded the proper range for the tensile strength of steel boiler plates (page 503), in this matter there certainly was a difference of opinion, and different limits were allowed by various authorities; but those who generally supervised the construction of high-class Lancashire boilers favoured the lower range given in the paper of 26 to 30 tons. In his own opinion plates which would bear a tensile load of over 30 tons were not as reliable as those a little below 30 tons, although a good extension gave an assurance of ductility. By following Mr. Halpin's suggestion of multiplying together the load per square inch in tons and the percentage of extension, a factor of from 600 to 700 would generally be obtained, while 800 as a limit would allow very hard plates to creep in.

The additional patch-strap (page 504) would no doubt overcome the difficulty of butt calking, and might be adopted in the shell of a marine boiler; but it would be inadmissible in the shell of a Lancashire boiler, because the latter was practically surrounded by hot flues, so that the shell itself was used as heating surface. A stop-water rivet had been recommended by Mr. Halpin (page 505), where the plates were butted together; and that was the very reason why it had been suggested in the paper that the plate corner should be thinned and extended until it reached the next rivet-hole. Wherever this could not be done, and there was the least space along which the water could pass, it was advisable to insert a stop-water rivet. If a thinned corner did not finish at a rivet-hole, it was sometimes found necessary to plug the joint with a soft iron or copper wedge, which though often invisible was only a clumsy job; and although the supervising engineer did not see it, it was often done.

The remarks respecting the stiffness of the Bowling hoop (pages 505 and 507) were scarcely applicable to the hoops of that name now made in steel at the Bowling Iron Works or the Bolton Iron and Steel Works, as these were now made of a lighter and more pliable section; and he knew of cases where hoops of the lighter

section, when properly applied, had withstood treatment which had destroyed the flanged seam.

From what had been said about calking and fullering, it would appear that the two were regarded as separate methods of making the joint tight; whereas the difference was in the tool only. Fullering really was calking with a broad-faced tool, making perhaps a neater finish, while it was still possible for the heel of the fullering tool to be as destructive and objectionable as a thin calking chisel. The tool spoken of as in use at Crewe works (page 511) was practically the same tool that had been used certainly twenty-five years ago by nearly all boiler makers, and was known as a "splitting" tool, because it was used to split the plate edge, just as at Crewe, and the inner split portion was afterwards calked by a tool of the same thickness as the splitting tool. At Crewe the splitting alone was found sufficient, which would no doubt be due to superior riveting. No matter how close the plates were before riveting, if too great a pressure was put on the rivet the overlap would spring open, especially if the overlap was too wide, or the heads of the rivets were too small in diameter. With rivet heads 1·6 times the diameter of the rivet, closed with a well-regulated load and held for a few seconds after closing, and an overlap not exceeding in width the diameter of rivet, the springing apart was minimised and less calking was required. If however the plates were well drawn together before and after drilling, and if the riveting were carefully done, he considered that the calking and fullering might yet be altogether dispensed with; and it was in this direction that improvements must be looked for, rather than by adopting machinery to do that which should be unnecessary. In several repairs which he had himself carried out, some of an extensive character, where calking of any description had been impossible, the joints had still been made drop-tight after riveting. In one instance half of a front end-plate had to be left uncalked on account of its edge being within three inches of brickwork which could not be removed; and several similar pieces of work had been made good up to as high as 140 lbs. test pressure, and had remained tight at 80 lbs. working pressure, by the judicious application of a layer of very thin canvass or gauze smeared with

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white lead. There should not therefore be much fear with new work, if a suitable paint or cement could be obtained to withstand the high temperature and the influence of the steam and water. Boilers of 3-8ths inch plates he had often seen made tight at a cold pressure without calking at the seams, and with nothing beyond a smear of oxide paint across the rivet-holes. It was universally admitted that calking could not strengthen a joint, and might weaken it; then why not try to dispense with it? And if cement could be so effectively used for engine-cylinder joints, why not experiment with it on boiler shells? The pneumatic calking tool could be looked upon only as in its experimental stage as yet; and it seemed strange that the thin calking chisel, to which there was such a strong objection, was the only tool he had ever seen the machine work with, and the tool with which it gave the greatest satisfaction.

With regard to the longitudinal attachments of the gusset stays (page 506), they were invariably fixed alternately on the first and second ring of shell plates from each end, as shown in the longitudinal section, Fig. 22, Plate 111, the riveting being well distributed, and never so close as to weaken the shell plate.

As to the desirability of removing the scale from the surface of the plates where they came together at the seams (page 506), this was the proper thing to do, so far as a close joint was concerned; but as all the shell plates went through the bending rolls, any scale of an appreciable thickness was shelled off, and nothing was likely to remain of importance. An acid bath or wash would certainly remove the oxide coating; but experience had proved beyond doubt that this thin oxide coating was the best protection the plate could have against the ravages of corrosion, caused by impurity of feed water.

The distance allowed between the lowest rivets in the gussets and the rivets in the furnace angles (page 507) was now seldom less than 9 inches in good practice, while a few makers allowed a breathing space of as much as $10\frac{1}{2}$ inches. Even 11 inches had been allowed without trouble or signs of distress: and he thought the extreme limits of safety had not yet been reached. Some means of staying might yet be introduced which would not necessitate securing the end-plates to each other by longitudinal bolt-stays, or yet to the

shell plates by gussets; it was for experience and experiment to decide. If a fairly stout front end-plate were adopted, and fitted to the shell with a flange of good section, and secured by double or triple riveting, a wider margin might be taken than when angle-rings outside the shell were adopted. The spacing of the circumferential joints was pitched by all good makers so that they should clear one another, as shown in the sectional plan, Fig. 28, Plate 113.

By the high test-pressure in page 500 of the paper was meant high in comparison with the ultimate working pressure. Thus if the calculated bursting pressure were 600 lbs. per square inch, a factor of 6 would give 100 lbs. working pressure, while a factor of 4½ would give 133 lbs. But those who insisted on a factor of 6 would require a test of double the working pressure; while those who were satisfied with a factor of 4½ would require only 1½ times the working pressure. Thus in each case the test-pressure would practically be the same, namely 200 lbs.; and this was what was being done with land boilers generally.

The results of Mr. Aspinall's experiments on clearing the burr from the rivet-holes (page 510) were in accord with his own views (page 490). The knife-like edge should be taken off, and that was what the simple bent or Z shaped rimer now exhibited would do very efficiently for both edges of the hole at once, without countersinking.

Instead of arriving by experiment at the proper angle for planing the plate edges to butt together (page 488), he had heard it suggested that a diagram might be constructed for showing the proper bevel. This however was practically impossible, because no two different kinds of bending rolls would give the same results; there would also be differences due to varying thickness, diameter, and manipulation of the plates.

A pertinent question with regard to the use of so many punching machines had been raised by Mr. Tweddell (page 512). There was no gainsaying the fact that many of these machines were still in use, and were doing better practical work than some engineers cared to credit them with. It should be borne in mind that the punching machine of today, with its slow steady movement and well proportioned punch and die, was no longer the barbarous machine of

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twenty years ago; and for all purposes where the plate surrounding the hole was not subject to a tensile strain, and where good quality of material was used, some boiler-makers preferred a punched hole. For instance the rivet-holes in the flue were all subject to compression, and the minute fractures said to occur during punching would never tend to open out: so that the actual loss of strength, if any, would be inappreciable, while it was admitted on all hands that a hole made by a well proportioned punch and die was of the correct shape. For such purposes as gusset rivet-holes, where the rivets were in tension, the tapering punched holes were in his opinion much superior to the parallel drilled holes. One great advantage of drilling was that it could be done after plates had been bent to shape and while they were in position, thereby ensuring good and fair holes. But while admitting this superiority of drilling, he shared Mr. Tweddell's opinion that too much was made of it.

From the samples of riveting exhibited there could be no doubt as to the superiority of machine riveting (page 512); and whether done by hydraulic or lever machines, it was to be preferred to that done by hand or by direct-acting steam-piston machines.

The flanged seams and flanged back end-plates that had been mentioned in the paper implied that few first-class works were without suitable flanging machinery. Even those makers who did not possess suitable flanging machinery sent out their work to be flanged elsewhere; and consequently the barbarous use of the mallet was now almost unknown. The pressed manhole mouthpieces (page 513) were useful and strong, and suitable for marine boilers; but they were not so convenient for Lancashire boilers as the mild-steel or wrought-iron manholes, of which so many were now manufactured.

The flanging outwards of the furnace holes in the end-plates (page 513) had given good results in short marine boilers, but not in the long Lancashire boilers. The end-plates so made were also more difficult to repair or remove than the plain flat end-plates; and owing to the heated gases passing out at the back end, such a plan would be inadmissible there, because the projecting joint would soon become overheated and fracture, and give trouble. Moreover such a

mode of construction did not lend itself to assisting in accommodating the uncontrollable force of expansion.

The option of testing boilers with or without the fittings in position (page 514) was due to the fact that many first-class boiler-makers did not supply fittings of their own make, these being frequently procured independently by the boiler owner; in such cases therefore the boiler-maker sometimes never saw the fittings. As it was always best to allow every maker to test his own production, the boiler had then to be tested with blank flanges on the mountings.

In addition to flanging the ends of the cylindrical flue-plates correctly at right angles, as pointed out by Mr. Jenkinson (page 515), attention had been drawn in page 493 of the paper to the need that the liner rings inserted in the circular joints should be rolled of a special section before bending, thicker along what was intended to be the outer rim than along the inner, so that when afterwards bent into a flat ring the two flat faces should be perfectly parallel. This was the more important, because in the flanging of the flue ends, the flanges were necessarily rendered thinner than the rest of the plate. When these flanges were brought together, with the liner ring between them, a stronger and more solid job was made if they were kept truly parallel to each other, as was the case when the flat faces of the liner ring were perfectly parallel after bending.

The object of the doubling plate under the manhole was to compensate for the material cut away, by adding an extra thickness all round the hole. The doubling plate became part and parcel of the shell plate, and could not possibly alter its form or straighten (page 507) without the shell plate doing so at the same time.

While sharing Mr. Marten's opinions generally (page 517), he had not been able himself in the period of twenty-six years from 1865 to 1890 to find more than 135 explosions of Lancashire boilers, out of a total of 1,330 explosions compiled in the accompanying Table (pages 530–532) by searching every known record. The difference might be due to the line of demarcation as to what really constituted a boiler explosion; and he had not included as actual explosions the mere bursting of pipes or the partial collapsing of furnaces.

TABLE (*continued to page* 532).

Steam Boiler Explosions during twenty-six years 1865–1890.

This list comprises only actual explosions of steam Boilers.
Failures of fittings, valves, pipes, economisers, &c., are not included.

Year.	Total number of Explosions.	Casualties.		Firing.		Types of Boilers.													
		Killed.	Injured.	Internal.	External.	Plain Cylindrical.	Cornish.	Lancashire.	Vertical.	Locomotive, Tram, or Traction.	Marine.	Portable.	Cylindrical, with flues.	Rastrick and Chimney.	Water-tube.	Other types.	Not ascertained.		
1865	55	56	82	34	19	12	7	7	2	11	2	2	..	..	..	10	2		
1866	75	87	152	46	18	12	11	11	6	6	5	4	3	2	..	4	11		
1867	55	88	81	28	14	10	9	6	..	3	1	2	3	..	..	8	13		
1868	53	57	60	34	19	13	8	7	2	4	3	1	1	5	1	8	..		
1869	63	92	142	34	24	23	14	8	2	3	3	1	..	1	..	3	5		
1870	66	82	127	39	18	13	17	6	4	3	3	1	..	2	3	5	9		
1871	55	53	103	34	17	15	8	6	4	2	5	2	1	1	..	7	4		
1872	62	35	102	28	31	18	11	5	4	5	3	..	2	3	2	6	3		
1873	66	56	80	35	27	15	15	2	2	5	5	2	..	1	7	8	4		
1874	68	71	171	41	23	13	21	6	5	3	5	1	4	4	2	..	4		
1875	50	67	116	30	17	12	8	8	6	2	4	..	3	..	2	2	3		
1876	40	95	113	26	12	7	7	8	..	3	4	2	..	1	..	6	2		
1877	47	53	65	32	14	10	11	5	5	2	4	2	1	2	1	3	1		
1878	52	49	85	34	14	8	10	6	4	5	7	1	4	1	1	1	4		
1879	46	44	58	26	18	13	5	3	5	5	4	2	3	..	2	2	2		
1880	36	71	94	24	11	4	10	6	2	2	1	3	2	3	2	..	1		
1881	36	40	47	24	9	6	10	6	5	1	1	1	2	1	..	..	3		
1882	39	37	45	31	8	6	7	5	9	4	4	2	2	..	..	..	..		
1883	42	31	57	34	8	8	11	5	8	3	2	3	..	..	..	2	..		
1884	37	24	49	28	8	4	10	1	8	4	1	3	1	2	..	2	1		
1885	38	33	57	28	8	5	4	4	11	3	4	1	2	..	1	1	2		
1886	41	31	79	30	10	7	6	3	9	3	7	3	1	1	..	1	..		
1887	40	21	42	27	3	2	7	2	11	6	6	4	..	1	..	1	..		
1888	46	19	47	38	8	5	3	2	19	7	5	..	..	1	1	2	1		
1889	64	25	65	55	9	8	9	3	18	8	15	1	..	..	..	2	..		
1890	58	18	60	49	9	8	10	4	16	3	12	2	..	1	1	1	..		
Total	1330	1335	2179	869	376	257	249	135	167	106	116	46	35	33	26	85	75		

TABLE (*continued on next page*).

Steam Boiler Explosions during twenty-six years 1865–1890.

This list comprises only actual explosions of steam Boilers.
Failures of fittings, valves, pipes, economisers, &c., are not included.

Year.	Causes of Explosions.														
	External Corrosion.	Over Heating.	Over Pressure.	Weakness of Flue.	Fracture.	Internal Corrosion.	General Deterioration.	Defective Stays.	Maleonstruction.	Grooving.	Deposit.	Weak Manhole.	Bad Material.	Safety Valve defective or absent.	Not ascertained.
1865	8	10	2	4	5	2	..	5	..	4	..	1	..	..	14
1866	9	8	12	8	8	..	..	5	..	1	..	4	1	1	18
1867	7	3	7	4	3	..	..	7	..	1	..	1	..	..	22
1868	5	6	1	6	8	..	1	8	..	1	2	1	..	..	14
1869	7	9	2	7	11	6	..	5	..	2	1	3	..	..	10
1870	7	13	10	9	5	7	1	6	..	1	2	..	..	..	5
1871	12	4	7	3	3	3	..	6	6	..	3	3	..	..	5
1872	8	7	8	7	4	4	1	..	1	2	2	3	3	2	10
1873	12	7	7	5	7	4	2	..	6	1	3	1	..	..	11
1874	9	10	7	15	2	2	2	..	8	1	..	3	1	..	8
1875	8	7	5	2	3	4	2	1	4	..	3	1	3	2	5
1876	7	5	2	3	2	1	4	..	5	..	1	..	..	1	9
1877	5	6	5	5	3	3	9	..	2	2	3	1	..	..	3
1878	9	7	1	4	3	3	7	3	2	6	..	..	..	..	7
1879	3	4	6	2	2	6	4	2	5	2	2	..	1	..	7
1880	7	8	5	1	2	4	3	..	..	2	1	..	1	1	1
1881	4	4	6	8	4	2	..	..	1	1	..	..	..	..	6
1882	6	3	8	2	1	4	3	3	3	2	2	..	..	..	2
1883	4	6	4	3	2	5	5	3	3	2	2	1	..	..	2
1884	9	4	4	5	1	7	3	..	1	..	..	..	1	..	2
1885	6	2	6	3	1	5	11	..	4	..	..	..	..	..	..
1886	14	5	3	1	..	11	2	8	4	3	2	..	1	1	1
1887	7	10	5	4	7	6	2	1	..	2	1	..	..	3	1
1888	6	7	4	3	2	12	10	1	4	3	3	..	1	1	1
1889	14	12	5	1	9	13	4	3	5	3	8	..	..	4	..
1890	15	15	4	5	5	12	2	3	4	1	5	..	1	1	..
Total	208	182	136	120	103	126	78	70	68	43	49	23	14	17	164

TABLE (*concluded from page* 530).

Steam Boiler Explosions during twenty-six years 1865–1890.

This list comprises only actual explosions of steam Boilers.
Failures of fittings, valves, pipes, economisers, &c., are not included.

Year.	Works at which Explosions occurred.																
	Mines and Quarries.	Iron and Steel Works.	Ships, Barges, Launches, &c.	Railways, Tramways, and Traction.	Cotton and Woollen Mills.	Agricultural.	Paper and Printing Works.	Saw Mills.	Pottery and Brick Works.	Corn Mills.	Bleach and Dye Works.	Chemical Works.	Dock and Water Works.	Breweries and Distilleries.	Contractors' and Builders' Works.	Metal and Machine Works.	Ship Yards, &c.	Miscellaneous.
1865	10	11	1	10	4	4	..	..	2	..	2	..	3	2	..	..	2	4
1866	12	11	8	6	4	2	4	3	..	2	..	2	2	2	..	..	..	17
1867	10	8	1	3	4	4	5	2	..	2	1	1	..	..	..	..	..	14
1868	10	8	5	4	4	1	1	3	2	..	2	1	1	..	..	..	..	11
1869	19	12	4	4	2	2	3	2	..	2	1	1	..	..	1	..	1	9
1870	13	10	4	3	3	..	4	2	2	1	1	2	..	1	..	1	1	18
1871	7	14	5	2	4	4	2	..	1	5	..	1	2	1	..	..	..	7
1872	15	9	3	6	5	..	..	1	3	4	2	3	1	..	..	..	..	10
1873	16	14	5	3	5	2	1	5	..	2	1	1	..	..	2	..	..	9
1874	15	11	5	3	7	..	4	2	1	2	3	4	..	..	..	2	1	8
1875	6	8	5	3	5	2	1	4	2	..	..	3	..	1	..	3	1	6
1876	5	8	5	3	4	1	3	..	3	1	1	1	1	..	1	..	..	3
1877	6	8	6	3	2	3	..	4	4	1	1	..	..	3	..	1	1	4
1878	9	9	7	4	4	3	1	1	1	2	..	1	1	1	1	..	..	7
1879	9	4	6	2	..	1	4	2	..	..	3	1	..	..	1	2	..	11
1880	5	10	2	2	..	2	..	..	3	2	2	1	1	1	..	1	..	4
1881	8	2	..	1	4	1	..	..	1	..	..	..	1	2	1	2	1	12
1882	5	4	5	4	1	4	1	..	1	2	2	..	1	..	1	2	..	6
1883	7	6	8	..	5	3	1	1	2	..	1	2	1	1	3	1	..	..
1884	2	10	3	2	..	4	2	..	1	..	1	..	..	1	4	1	..	6
1885	3	8	8	..	..	5	..	2	3	2	2	..	1	2	1	..	..	1
1886	7	4	12	2	..	7	1	3	..	1	..	..	..	1	..	2	..	1
1887	2	4	11	6	2	3	..	2	1	2	1	1	1	1	3	..	..	..
1888	2	4	17	6	..	3	..	4	..	2	..	1	..	..	..	5	1	1
1889	7	7	24	9	3	4	..	1	2	2	..	..	1	..	..	3	..	1
1890	3	7	19	1	1	6	1	2	4	4	..	..	..	1	1	3	..	5
Total	213	211	179	92	73	71	39	46	39	41	27	27	18	21	20	29	9	175

The bulging of the steel boiler-plate (page 517) in the test illustrated in Fig. 9, Plate 109, was done as follows. The plate was placed flat and cold under a hydraulic press, and forced into an irregular shape, the centre being depressed about 1½ inch in about 12 inches diameter. It was then made hot at the bulge, and hammered back to its original flat form by mallets, and then cut into strips and tested as described.

In the use of horizontal bending rolls (page 517) he did not see any cause for fear, as the weight of the plate was generally carried from above; but the vertical bending rolls were perhaps more convenient.

With reference to big plates (page 518), it must be remembered that, in rolling wide plates thinner than ⅞ or ¾ inch, neither the thickness nor the weight could be guaranteed. Not only so, but there was also another question to be considered. Wide plates might be all very well in themselves, and a boiler shell made all in one piece might be all very well; but unless the boiler was constructed at the steel works, how was a plate 25 feet long and 25 feet wide going to be conveyed flat from the rolling mill to the boiler yard? It could neither be carried on the railway trucks, nor could it be got under the railway arches. That was the difficulty already experienced in the midland towns, where marine boiler work could not be touched because of the impracticability of carriage.

Double riveting (page 518) he had avoided alluding to in the paper, knowing that triple or even quadruple riveting was necessary to get the high percentage of strength of joint. Following in the wake of many others, he had left it open to the boiler-maker to use such a pitch as would bring up the strength of the joint to what was wanted. Unless properly designed, triple riveting did not in itself mean a stronger joint than double riveting. No doubt the solid weldless rings, which up to now had really been forgings, might in time become marketable; but many improvements would have to be made before they were profitable, on account of the difficulty of handling them during construction.

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The lamination that was due to the presence of blow-holes (page 521) he believed was generally slight, and of less importance than lamination due to impurities. The defect arising from working the steel at a blue or rotten heat (page 521) was not so much felt, owing to the introduction of improved flanging machinery; but where hand-work and short heats were resorted to, the evil prevailed as badly as ever. The metal must be either hot or cold; to attempt to work it between these limits was dangerous.

If the rivet-holes of the longitudinal seams were drilled before bending the plates (page 522), the defect suggested by Mr. Head would certainly be experienced; but this was seldom if ever done. As regarded steel and iron rivets (page 522), when carefully heated and closed in with a proper load he considered the steel rivets were to be preferred. It was certainly true that they were worse to remove when repairs were necessary; but on the other hand it might be said, the better the riveting, the tighter would be the seams, and the less likelihood would there be of repairs.

As long ago as 1872 he had used a set of horizontal bending rolls in which the top and front rolls were so close as to carry the sweep to the extreme end (page 523); but as the adjusting roll was at the back, it necessitated reversing the plate in the rolls. These very rolls, though on that account slightly inconvenient, were still in use. The handiest and perhaps the best rolls at present in use were the group of four vertical rolls, three of which were adjustable, and one was fixed. These carried the sweep to the extreme ends without reversing the plate in the rolls. There was no doubt that any of the large machine-makers would now produce rolls giving similar results.

In conclusion it should also be remembered that the boiler-maker, whatever was his practice, was not always allowed to have his own way, but had to work to the specifications of other engineers.

The President said that in connection with the present paper he could not help calling to mind how largely the great improvement of Lancashire boilers and stationary-engine boilers was due to the services rendered to mechanical engineering by their late Vice-President, Mr. Daniel Adamson. He himself was old enough to

remember when boilers were made altogether by the rule of thumb; the parts were put together and fastened in so crude a manner that the finished boilers were little better than sieves. Years ago Mr. Adamson had taken a great deal of trouble with boiler making: to him was largely due the introduction of steel into the manufacture of boilers, at a time when the use of steel for this purpose was far from popular; and no small amount of confidence was required to advocate such a procedure. Tenacity of purpose however, and the courage of his opinions, were leading features in Mr. Adamson's character; and he had lived to see his views approved and adopted far and wide with the greatest advantage to all concerned. He was sure therefore that the Members of this Institution could not listen to a paper like that now read without paying a tribute of gratitude to Mr. Adamson for all that he had done to put boiler making on a scientific footing. Having himself been brought up originally in the same shops as Mr. Adamson, he had known him nearly all his life, and entertained the greatest respect for his memory; and in listening to this paper he could not help recalling the efforts that Mr. Adamson had made to produce boilers like those in use at the present time. He had now much pleasure in proposing a vote of thanks to Mr. Boswell for his paper, and for the useful practical hints which he had given. These he had no doubt would be found advantageous in facilitating anything that might be done still further to improve the construction of Lancashire boilers.

Mr. Edward G. Hiller wrote that the paper appeared to him to be valuable, partly as indicating the way in which some of the recognised imperfections of the Lancashire boiler may be overcome, but more as to some extent summing up the improvements which have been effected and which are now generally adopted by the best makers in the construction of such boilers. It is in detail certainly that improvement is to be observed; for in general form and proportions the Lancashire boiler of today differs little from that of

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about twenty years ago. About that time the ruling size of boilers for cotton mills was 28 to 30 feet length by 7 feet diameter, and the safety-valve load was from 60 to 80 lbs. per square inch; while today the improvements in the details of construction and in the material have enabled boilers to be constructed for 100 to 150 lbs. working pressure with as much confidence as previously for 80 lbs., and the ruling size for the best mill boilers is 30 feet length by 8 feet diameter with 100 lbs. pressure per square inch. There appears to be a general tendency to higher pressures; many boilers are being constructed for 150 lbs., and some for even 200 lbs.

The main features in which the modern boiler differs from the earlier are:—firstly, in the use of steel instead of iron for its construction; secondly, in the drilling of the rivet holes after the plates have been bent, instead of punching them before bending; and thirdly, in the general adoption of the Adamson flanged joint, or some other effective mode of strengthening the flue tubes.

The steel plates manufactured for boilers appear to be generally well adapted for their intended purpose, being of high tensile strength, ductile, and usually free from liability to be rendered hard by overheating. The tensile strength given in the paper, of not less than 26 tons per square inch and not more than 30, is quite satisfactory for shell plates; but where the flue plates are to be lap-welded and each ring afterwards flanged, it is generally preferable to require a tensile strength of 24 to 28 tons, with a view to obtaining a material better suited to stand the flanging, and easier to weld. The usual mode of testing the strips, although apparently ensuring satisfactory results generally, appears hardly to be based on scientific grounds, since the whole of the elongation is measured, including the local necking down which takes place shortly before rupture. A fairer basis of comparison would be to take account of the elongation up to the point of maximum total load, thereby avoiding the influence of the local stretching which takes place after that point has been reached. The bending test depends on the manner in which it is carried out; the use of proper clips and levers to bend the strips gradually is much more likely to give satisfactory results than when the bending is done under the steam hammer.

The butt joint with double straps is undoubtedly the best seam for the longitudinal joints, and should be invariably adopted for pressures of 80 lbs. and upwards. By the direct transmission of the stress any such change of form under varying pressures as is inevitable with lap joints is avoided; while the fact that, when the rivets fill the holes, any leakage has to pass through at least double the distance compared with a lap seam, greatly reduces the liability to leakage. In the method of finishing the junction of the longitudinal butt joint and the ring seam the practice of good makers varies. Many thin the ends of the straps and tuck them under, in the manner described in the paper; and this is generally the easier plan for making a tight joint. The other plan, of butting the ends of the straps against the ring seam, requires careful fitting, and by some of the best makers is regularly and successfully done. In the arrangement of the riveting in the longitudinal seams there is some diversity of practice. Double chain-riveting is used in some cases, double zigzag in others. As a general rule the zigzag arrangement is preferable, because it minimises any danger of leakage. But tight work is obtained with the best chain-riveting; for instance, with 3 inches pitch of 13-16ths inch rivets (finished size), in shell plates 9-16ths inch thick and butt straps 7-16ths inch thick, for 100 lbs. working pressure; and this method admits of a neater finish at the ring seams.

The shell ring seams are of especial interest, inasmuch as the practice is by no means uniform for high pressures. Thus for pressures of 120 lbs. and upwards many boilers are now constructed with double-riveted ring seams. This is certainly quite unnecessary, so far as strength is concerned; whether it is really necessary for preventing leakage, experience will show; but it must be remembered that the double thickness of thick plates increases any liability to overheating; and where deposit is present in the boiler and the flue gases are at a high temperature, the double-riveted seam will be more liable to burning and fracture.

From the experiment quoted in regard to local heating (page 487) it is apparently argued that there is little danger to be feared from local heating of steel boiler plates of the proper quality. This is probably true in general, and doubtless the stipulations in respect to

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testing by local heating arose from the harder steel plates at first used, which in many cases were liable to hardening when so treated. At the same time, seeing that the heating is not absolutely necessary and in the working of the boiler ought properly never to occur, it is better to avoid it as far as possible in construction.

Although in the best work drilling is invariably adopted for the rivet holes, punching is yet advocated by some boiler-makers on the ground that the taper form of the holes when properly made assists the rivets to nip the plates together; and at the same time there is little doubt that careful punching does not materially injure the soft steel plate adjacent to the holes. All punching however has to be done before the plates are bent to form; and the bending after punching is liable to cause undue bend at the line of rivet holes, and this in the case of hard plates has probably been the cause of some few explosions. Drilling on the other hand is done after the plates have been bent to form, thereby avoiding this danger; and the holes being uniform and truly opposite each other, the rivets fill them more easily, tending to prevent leakage and to ensure equal distribution of the stress.

For the flues 7-16ths inch has generally been the maximum thickness of the plate with flanged seams, until recently; and the plates have usually been lap-welded. The welds obtained in this manner generally appear to be sound, but often somewhat rough in finish. For thicker plates and higher pressures, the weld made with a glut piece inserted between the edges of the plates certainly appears to be more satisfactory; but to finish a weld in first-class style by this method or the other requires special appliances, such as are not to be found in many boiler works. To obtain really circular flues, say within 1-8th or 3-16ths inch of the true circle, the flue rings require resetting after welding; and to anneal them thoroughly, the whole ring should be heated to a dull red. But this is seldom done; and indeed with the great strength of the Adamson flanged joint it would appear that a deviation of $\frac{1}{4}$ or $\frac{3}{8}$ inch from the true circle may in ordinary cases be safely allowed.

Of the modes of strengthening the flues, the Adamson flanged joint is that most generally adopted. It is available for all makers,

and the machinery necessary for its construction is comparatively simple, while when made with proper care the joint is one of the best modes of forming a strong flue. The flanges and calking rings form practically rigid abutments, which greatly strengthen the flue in ordinary work, and in the event of overheating are invaluable. As a working seam the great advantage of this joint is that, when the flue is welded longitudinally, no rivets at all are exposed to the flame. The statement in page 193 that a flange at each seam gives an excess of strength may be true for a particular furnace:—thus with a flue 3 ft. 2 ins. diameter, 7-16ths inch plates, and 100 lbs. pressure, flanged joints 3 feet apart will give an ample margin of strength. For higher pressures however the flanged joints should of course be nearer together, their distance depending also upon the thickness of the plates. For all pressures above 60 lbs. the flues should certainly be strengthened by hoops or flanged seams; and any proposal to dispense with such supports at higher pressures would show that careful supervision was needed (page 194) not only of the construction but also of the design. The Bowling or Bolton hoop, though a good means of strengthening flues, is more expensive than the flanged joint; such hoops require great care in shrinking on, so as to ensure a tight joint and at the same time to avoid straining the hoop. The Davey-Paxman and the Hawksley-Wild seams are also successfully used for high pressures. In both of these the whole of the plate is exposed to the water on one side and to the fire on the other, tending to uniform expansion; whereas in the Adamson flanged joint the body of the flue is exposed to the fire, while the flanges are in water only; hence the body tends to expand radially more than the flanges, setting up a movement at the bend of the flanges, which under some circumstances will result in grooving. Fox's corrugated flues have been used in Lancashire boilers, though not to the same extent as in marine; but until recently the writer believes the Purves flue has not been applied to Lancashire boilers, for the furnaces of which it would appear especially suitable at high pressures.

The ends of Lancashire boilers not exceeding 8 feet diameter and not above 200 lbs. pressure need not be more than 5-8ths inch thick; and the principle of staying them should be to secure a practically

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rigid end outside the breathing circle of each furnace. For the breathing consequent upon the expansion of the flues there should be from 8 to 10 inches distance above the flues, between the nearest gusset-stay rivets and those attaching the flues to the ends; and below the flues, where the expansion is less, 4 to 6 inches will be sufficient. The paper appears to advocate setting out the gusset stays so as to secure a nearly equal distribution of stays on the end plates. This would be satisfactory, if the necessary setting of the angles, consequent upon the gussets not being radial, could be easily and accurately carried out: but experience rather points to difficulty in this respect. Generally the finish of the gusset stays is one of the least satisfactory features; and it would appear better to place the gussets radially, and thereby avoid any such difficulty as the other course entails, especially as radial gussets can be arranged practically to give ample support to the ends. Gusset angles are difficult to set accurately; and the attempt to alter them from the right angle often results in their gaping open from the gusset plates and not gripping them. For boilers of $7\frac{1}{2}$ or 8 feet diameter, five gussets above the flues are usually adopted; but four gussets properly arranged are really quite satisfactory, at least up to 150 lbs. pressure per square inch. For higher pressures special care is needed in arranging the riveting of the gusset angles to the shell plates, in order that the longitudinal section through the gusset rivet-holes shall not fall below the percentage strength of the longitudinal seam.

The argument referred to in page 490, that the hydraulic test is of little use, has been in connection, the writer thinks, with the employment of this test as a criterion of the condition of old boilers. For old boilers the hydraulic test is a useful check upon the complete examination which must always form the basis of any reliable opinion as to the strength of an old boiler. In such cases the test by itself is certainly not reliable: the effect of the steady water-pressure is quite different from that of the varying steam-pressure, which in ordinary work is combined with severe stresses due to unequal expansion. Only too often, where the hydraulic test alone has been relied on, has explosion taken place at a pressure considerably below the hydraulic test which had previously been successfully withstood. The hydraulic

test however is always useful for ascertaining the tightness of riveted work and of the boiler generally, and also as regards the efficiency of the staying of the flat ends; and for this purpose it is most valuable for new boilers.

The questions of construction, dealt with by the author, are generally so nearly connected with that of design, which is considered in some of its relations, that the writer thinks the value of the paper would not have been diminished, had the latter question been touched upon in further detail; and the subject would thereby have been rendered more complete.

Mr. Alexander Turnbull wrote about the mounting blocks or stand-pipes referred to in page 499 of the paper, where it is mentioned that steel castings have been broken in bedding to the plate, and are sometimes so porous as to give much trouble in leakage. Such castings are of a kind which were too often supplied some time ago, but great improvements have recently been effected in their manufacture; and as himself a manufacturer of the superior steel castings now largely produced, he is surprised to hear of the former inferior castings being still made.

Mr. George Ratliffe wrote that, so far from steel castings being unsuitable for manhole seatings of steel boilers (page 499), a great number are now employed, some of which have been in use for a long time. It is true that some have been better made than others; but many steel founders are now capable of producing perfectly reliable and sound castings, which will pass successfully all the tests required by the Admiralty and the Board of Trade.

Dr. Alexander C. Kirk wrote that he feared but little attention was often given to the importance in machine riveting of keeping the pressure on the rivet till the red heat was gone, and the body of the rivet had acquired strength sufficient to retain the plates in close contact after the pressure was removed, so that they might then be drawn still closer together during the further cooling and shrinkage of the rivet. The thicker are the plates to be riveted, the more

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important is this point; the plates of $1\frac{1}{4}$ to $1\frac{3}{8}$ inch thickness now used for boiler shells have often a considerable tendency to draw apart after riveting, and much bad and leaky work is the consequence if the pressure of the riveting machine is prematurely taken off. There is no doubt that Mr. Edwin Clark was quite right when he attributed the absolute immobility of riveted joints under working strains to the friction produced between the plates by the intense grip of the rivets; and absolute immobility of the joints is essential to their remaining water-tight while at work. Though the friction of the joints may be insufficient during a water test, for instance, and the plates may slip a little, they may yet be made quite water-tight by calking; but in the actual working of a boiler the joints are subjected to reciprocating strains by unequal expansion and contraction, and under these circumstances if they slip backwards and forwards, although but a hair's breadth, they quickly become leaky. The writer makes it a constant practice to throw a small jet of cold water upon the plates on both sides, while the pressure is continued on the rivet. This has the double effect of keeping down the heating of the plates, and also of ensuring that a certain delay takes place before the pressure is released. In order to maintain water-tightness in marine work, treble riveting is often applied to circumferential seams, which are often strained by unequal expansion; whereas the proper course would be to see that the plates are held together firmly enough by the single row of rivets which is sufficient for the strength of a circumferential joint.

Mr. Boswell wrote that he was in accord with the opinions expressed by Mr. Hiller (pages 535–541), who had gone into some details more fully than the paper itself would admit of. He was glad to hear that the manufacturers of steel castings had now such confidence in their productions (page 541); but up to the present he had had just cause to complain.

REPORT TO THE ALLOYS RESEARCH COMMITTEE.

By Professor W. C. ROBERTS-AUSTEN, C.B., F.R.S.

At the request of the Alloys Research Committee I began in April 1890 to investigate the effects of small admixtures of certain elements on the mechanical and physical properties of Iron, Copper, and Lead. The Committee desired me to extend an investigation I had previously made upon the application of the "periodic law" of Newlands and Mendieleef to the mechanical properties of metals. This law, as originally expressed, states that "the properties of the elements are a periodic function of their atomic weights." It had already been shown that the effect of impurities added to gold is nearly proportional to their atomic volume, the larger the volume of the atom the greater being its effect;* and it became interesting to determine whether this holds good for other metals.

The Committee considered it desirable that iron should be the metal first examined; but the problem has fortunately been attacked by M. Osmond,† the results of whose recent investigations have gone far to show that there are two distinct varieties of pure iron, the α or soft and the β or hard form; and further that the action of impurities on iron does appear to be in accordance with the periodic law. The foreign elements, whose influence on the critical points of iron he has studied experimentally with more or less completeness,

* Philosophical Transactions of the Royal Society, vol. 179, 1888, p. 339.

† Comptes Rendus, vol. cx, 1890, p. 346. The results of his experiments are given in detail in the Journal of the Iron and Steel Institute, 1890, part 1, p. 38.

are ranged as follows in two columns in the order of their atomic volumes, found by dividing their atomic weight by their specific gravity:—

I.		II.	
Carbon	3·6	Chromium	7·7
Boron	4·1	Tungsten	9·6
Nickel	6·7	Silicon	11·2
Manganese	6·9	Arsenic	13·2
Copper	7·1	Phosphorus	13·5
		Sulphur	13·7

He points out "that the elements in column I, whose atomic volumes are smaller than that of iron (7·2), delay during cooling *cœteris paribus* the change of β or hard iron into α or soft iron, as well as that of "hardening carbon" (*carbone de trempe*) into "carbide carbon" (*carbone de recuit*). For these two reasons they tend to increase, with equal rates of cooling, the proportion of β or hard iron that is present in the cooled iron or steel, and consequently the hardness of the metal. Indeed their presence is equivalent to more or less energetic hardening produced by rapid cooling. On the other hand, elements whose atomic volumes are greater than that of iron (column II) tend to raise, or at least to maintain near its normal position during cooling, the temperature at which the change of (β) hard to (α) soft iron takes place. Further, they render the inverse change during heating more or less incomplete, and usually hasten the change of dissolved or "hardening carbon" to "carbide carbon." Thus they maintain iron in the (α) soft state at high temperatures, and must therefore have the same effect in the cooled metal. In this way they would act on iron as annealing does, rendering it soft and malleable, did not their individual properties, or those of their compounds, mask this natural consequence of their presence. The essential part played by foreign elements alloyed with iron is therefore either to hasten or to delay the passage of iron during cooling to an allotropic state; and to render the change more or less incomplete, in one direction or the other, according to whether the atomic volume of the added impurity is greater or less than that of iron. In other words, foreign elements of low atomic volume tend to make iron itself assume or retain the

particular molecular form which possesses the lowest atomic volume, whilst elements with large atomic volume produce the inverse effect.

It will be evident that if iron itself can exist in two widely different states, each with properties of its own, the mechanical properties of given samples of iron and steel must depend upon the relative proportions of the two modifications of iron present in the mass. And it will also be evident that the nature of the influence of impurities on iron is far more complicated than in the case of gold, their primary effect on iron being either to hasten or to delay the passage of the metal from its normal state to another, which possesses widely different molecular aggregation, and consequently different properties. In the case of gold, it is possible that the molecular constitution of the precious metal is simpler than that of iron; each molecule may consist of but few atoms, and therefore there may not be the same scope for pronounced change of properties which could follow re-arrangement of atoms in the molecules. The action of an impurity may probably be more direct in the case of gold, as its influence is not initially exerted in re-arranging the atoms in a molecule, but in affecting the mutual relations of the molecules themselves. Or it may be that the lowering of the freezing point, which is effected by the presence of impurity, may enable the cooling gold to assume a crystalline structure which is detrimental to its tenacity, if not destructive of it.

The difficulties of obtaining for mechanical tests masses of iron with only definite amounts of a single impurity are very great, and it is therefore very difficult to extend Osmond's research; but of the practical importance of his experiments there can be no question, and their full significance may become more apparent by investigating the action of impurities on some other metal, the behaviour of which suggests strong probability that it can exist in an allotropic state. In view however of the importance of Osmond's research, it was considered desirable to confirm his main results, adopting an independent method of observation, as will be stated subsequently.

Lead, which is one of the metals the Committee selected for investigation, probably exists in more than one modification.

Muschenbroeck and afterwards Guyton de Morveau * showed that the cohesive force or tenacity of lead is increased by hammering or drawing; and the latter speaks quite clearly of molecular strain produced by the mechanical treatment. Bolley † has shown that "chemically active" lead may be prepared by electrolytic action; and W. Spring ‡ has gone far to show that the polymerization (or increase in the number of atoms in a molecule) of lead-tin alloys may take place at temperatures below their melting points. The observation made by Coriolis,§ that lead increases in hardness by successive meltings, even if protected from oxidation, may not be without significance. I have made a great many experiments on the mechanical properties of lead as affected by a small quantity of impurity; but as yet it has not been found possible to obtain definite or even concordant results. The tenacity and extensibility of lead seem to be greatly influenced by the temperature at which the metal is cast; and the difficulty of avoiding the presence of flaws and blow-holes is very great. This portion of the enquiry has therefore been set aside for the present, as it is probable that more valuable evidence of allotropic changes will be afforded by thermal than by mechanical measurements.

Pyrometer.—In order to carry out the investigation, a really trustworthy Pyrometer is required. The admirable investigations of Callendar ‖ with the pyrometer of Siemens have restored the confidence in it which had been shaken by a Report of a Committee of the British Association.¶ The action of this instrument depends on the variation of resistance presented by a heated platinum wire placed in one branch of a divided circuit; and it is trustworthy for temperatures up to 500° C. or 900° Fahr. Messrs. Callendar and Smith ** have shown that with platinum resistance thermometers a

* Annales de Chimie, vol. lxxi, 1809, pp. 189–199.

† Liebig und Kopp, Jahresbuch, 1849, p. 278.

‡ Bulletin de l'Académie Royale de Belgique [3], vol. xi, No. 5, 1886.

§ Annales de Chimie et de Physique, vol. xliv, 1830, p. 103.

‖ Philosophical Transactions of the Royal Society, vol. clxxviii, 1887, p. 161.

¶ Report of the British Association, 1874, p. 242.

** Proceedings of the Royal Society, vol. xlviii, 1890, p. 220.

degree of accuracy of the order of 0·01° C. or 0·02° Fahr. may be attained at temperatures between 100° and 450° C. or 212° and 840° Fahr.

In the present investigation it is necessary to measure much higher temperatures; and fortunately an accurate method is at hand. Early in 1889 I had occasion to employ the pyrometer devised by M. H. Le Chatelier, and was satisfied as to its being extremely trustworthy and convenient up to temperatures over 1,000° C. or 1,800° Fahr. The instrument in fact enabled me to confirm the fundamental observations of M. Osmond respecting the critical points of iron and steel, and to demonstrate the results in a lecture delivered before the members of the British Association in September 1889.* Le Chatelier's pyrometer I believe had not previously been employed in this country; and it may be well to describe it in some detail, as such an instrument has long been needed, and can hardly fail to be of much use to engineers. The pyrometer † consists of a thermo-couple of platinum, and platinum containing 10 per cent. of rhodium. Thermo-couples have long been used; but, as is pointed out by Barus ‡ in an elaborate memoir only recently published, the earlier investigators unfortunately employed unsuitable metals, iron and palladium, which, from the readiness with which they absorb gases and consequently undergo molecular change, are of all metals probably the least suited for thermo-electric pyrometry. Osmond's work alone would show that iron is specially unsuitable for high-temperature thermo-couples. Le Chatelier's pyrometer is based on the measurement of the electric current produced by heating a thermo-junction inserted in a circuit with a galvanometer of considerable resistance. As already stated, this thermo-couple consists of two wires, each about 0·5 mm. or 0·02 inch diameter, one of which is of pure platinum, and the other of platinum containing 10 per cent. of rhodium. The junction of the wires may simply be effected by twisting them together in either of the forms indicated by the sketches, Figs. 3 and 4, Plate 116.

* 'Nature,' vol. xli, Nov. 1889, pp. 11, 32.

† Journal de Physique, vol. vi, Jan. 1887, p. 23.

‡ Bulletin of the United States Geological Survey, No. 54, 1889.

The junction may be welded, or soldered with gold, no flux being used; but neither of these methods seems to possess any advantage over a double twist. This junction may be viewed as a battery; for when it is heated a current of electricity is generated, no other source of electricity being employed. It is asserted that even long wires of the platinum-rhodium alloy are homogeneous, and therefore do not give rise to subsidiary currents, which would disturb the effect of the main current produced by heating the junction; but very careful experiments to determine whether this is the case have yet to be made. From analogy with platinum-gold alloys, it may be doubted whether the platinum-rhodium alloy is of absolutely uniform composition. The thermo-electric properties of platinum-rhodium wire are said to be hardly altered by stress, or by exposure to rapid alternations of temperature; nor does the nature of the gaseous atmosphere in which the couple is placed appear to render its action untrustworthy. The present experiments have shown that the wires must certainly be protected from the vapour of silver, or from contact with carbon or silicon. The free ends of the platinum and platinum-rhodium wires are soldered to copper terminals, which are kept at a constant temperature by being plunged into test tubes, filled with alcohol and immersed in water, the temperature of which can be observed with a thermometer. The thermo-couple measures the difference of temperature between its heated junction and the copper terminals.

The galvanometer which appears to be best suited for use in connection with the couple is a reflecting dead-beat one, which bears the names of Déprez and d'Arsonval; it is now well known in this country. That employed in the following experiments* has an internal resistance of 200 ohms. The arrangement of the several parts is shown in Fig. 5, Plate 116, in which U is a magnet, B a coil of wire suspended by a german-silver wire SS and moving freely round an iron core C, and M is a mirror carried by the same wire S. The steadiness of the spot of light upon the screen when the circuit is closed is remarkable.

* Constructed by M. Carpentier, 20 Rue Delambre, Paris.

Graduation of Pyrometer.—The electromotive force produced by heating the thermo-junction to any given temperature is measured by the movement of the spot of light on the scale graduated in millimetres. A formula for converting the divisions of the scale into thermometric degrees is given by M. Le Chatelier; but it is far better to calibrate the scale by heating the thermo-junction to temperatures which have been very carefully determined by the aid of the air thermometer, and then to plot the curve from the data so obtained. Many fusion and boiling points have been established by concurrent evidence of various kinds, and are now very generally accepted. The following table contains thirteen of these:—

212° F.	...	100° C.	Boiling point of water.
618°	...	326°	Melting point of lead.
676°	...	358°	Boiling point of mercury.
779°	...	415°	Melting point of zinc.
838°	...	448°	Boiling point of sulphur.
1157°	...	625°	Melting point of aluminium.
1229°	...	665°	Boiling point of selenium.
1733°	...	945°	Melting point of silver.
1859°	...	1015°	„ „ potassium sulphate.
1913°	...	1045°	„ „ gold.
1929°	...	1054°	„ „ copper.
2732°	...	1500°	„ „ palladium.
3227°	...	1775°	„ „ platinum.

The known temperatures employed for calibrating the thermo-junction referred to in this Report are the boiling point of water 100° C., the melting points of lead 326°, zinc 415°, and aluminium 625°, the boiling points of sulphur 448°, and selenium 665°, and the melting point of potassium sulphate 1015°. The melting point of silver 945° is one of the points which rests on more evidence than any other; I find however that, when it is carefully determined and interpolated in the curve, the number is only 920° C.; this is doubtless owing to retention of gas by the metal. The melting point of gold 1045° C., and Violle's* determination of that of palladium

* Philosophical Magazine, vol. viii (series v), 1879, p. 501, and vol. xiii 1882, p. 147; Comptes Rendus, vol. lxxxix, No. 17, pp. 702, 703.

1500°, are generally accepted. These several fixed temperatures have been used as the basis of the calibration.

In Fig. 2, Plate 115, some of these temperatures are taken as ordinates, while the abscissæ are the deviations of the spot of light which marks the temperature at the thermo-junction. It will be evident, since these points fall so close to an even curve, that much confidence may be placed in the trustworthy nature of the pyrometer. It may be noted that the position here marked for the boiling point of water, namely at about 90° C., is of course not the true boiling point of water, but is the difference between the true boiling point 100° C. and the observed temperature 10° C. of the cold junction of the pyrometer. In the various determinations the latter temperature varied from 10° to 15° C., or 50° to 60° Fahr.

It was hardly to be expected that the determination of the melting point of palladium would yield a figure which falls so fairly into line with lower melting points; and it may be well to add a few details as to the manipulation. A globule of palladium weighing about 2 grammes or 30 grains may readily be melted by placing the metal in a cavity in a sound piece of charcoal. The charcoal near the button is ignited, and a stream of oxygen from a fine clay tube about 1 mm. or 0·04 inch diameter is directed into the cavity. A very manageable source of intense heat is thus obtained; and a fused globule of gold or palladium may be tilted on to the junction conveniently placed in the cavity, and then allowed to cool there. The globule may in fact be melted on or shaken off the junction as readily as a drop of wax; and the slight arrests of the spot of light, which mark the true points of fusion and solidification, can readily be detected by a practised observer. It has already been shown by M. Le Chatelier that soldering the junction with gold in no way diminishes its sensitiveness; and this appears to be true of palladium. The wires however, after brief exposure to the alloying metals at this very high temperature, rapidly become destroyed and broken. In some cases, as in that of determining the melting point of potassium sulphate, the thermo-junction may be plunged without covering into the midst of the mass, which is gradually being raised to its fusion point. In the case of a metal, the thermo-junction may

either be surrounded by a portion of the metal; or a strip or globule of the metal may be placed in a crucible filled with some substance difficult of fusion—silica or calcined magnesia—in close proximity to the thermo-junction. The temperature is very gradually and steadily raised, until the metal begins to fuse; a Fletcher oxygen furnace answers well. The moment at which fusion begins is indicated by an arrest in the movement of the spot of light; followed, if the mass of metal be small, by a rapid forward movement when the fusion is complete. The point that the spot of light has attained on the graduated scale at the moment of its arrest is the point to note as the melting point of the metal. A little practice will enable this point to be readily determined; but all uncertainty in the matter is removed by reducing the spot of light to a fine vertical line, and securing a photographic record of its movement.

The following plan may therefore be recommended when a high degree of accuracy is required. The vertical line of light, from an argand gas burner L and mirror H, Fig. 1, Plate 115, is reflected from the mirror M of the galvanometer, and is allowed to fall upon a sensitized plate through a carefully adjusted horizontal slit A B; Eastman's gelatine films have been found to answer well. The slit entirely crosses the plate, which is made to travel upwards at a uniform rate by gearing D driven by clockwork; the regularity of the rate of travel may be tested by a time-signal in seconds, produced by periodically obscuring, by the interrupter E worked by a clock, the light from a second fixed mirror F placed immediately below the suspended mirror M of the galvanometer, so as to send a fixed beam of light to the zero of the galvanometer-mirror scale, that is, to the further end of the horizontal slit AB. The amplitude of the deflection of the galvanometer mirror M will of course depend on the temperature to which the thermo-junction T is heated. The same source of light illuminates both mirrors; and the result is, first, a beaded datum-line from the intermittent light of the fixed mirror F, which gives the rate of travel of the plate; and second, a continuous curve which is photographically traced by the line of light from the galvanometer mirror M, this photographic curve being the resultant of the movements of the tiny spot of light and of the sensitive plate. The

sketch shown in Fig. 1 is about one-twelfth of the actual size of the pyrometer employed in connection with this Report.

The nature of the photographic curve in the case of a melting point may be illustrated by that which represents the fusion and solidification of a mass of aluminium weighing 10 grammes or 150 grains. The thermo-junction was in this case protected by a thin covering of pipe-clay 1 mm. or 0·04 inch thick. While the plate is at rest, the spot of light traces the straight line *ef*, Fig. 9, Plate 116 ; then as the plate advances it traces the somewhat sinuous curve *fg*, owing to the necessarily irregular heating of the mass of metal ; but it is arrested at *a* when fusion begins, and a line parallel to the datum line is traced until the mass is fluid, when the temperature is raised above the melting point, as is shown by the portion of the curve marked *b*. The gas being then turned off, the metal cools and freezes, as is indicated by the second arrest *c*, at a point slightly below its melting point.

It will be evident that a chronographic record might replace the photographic one. In fact in beginning the investigation the chronographic method was employed. The time taken by the spot of light from the galvanometer to pass each division of a transparent graduated scale was noted on the paper ribbon of a delicate Bain instrument by an electric signal, side by side with a series of electric time signals from a clock beating half-seconds. This method, though very delicate, involves much labour in the translation of the ribbon and in plotting the curves, and is therefore much less convenient than the photographic one, which gives a curve automatically.

The calculations by which the final results are obtained are as follows. From the curve representing a particular experiment the temperature of any point of interest may be obtained by reference to the calibration curve. This temperature has to be corrected, first, for error e in indications of the galvanometer, due to change of its temperature ; and second, for alteration j in the temperature of the cold junctions.

The measurement of temperature by the thermo-junction depends, as is well known, on the measurement of an electromotive force by means of the current set up in a circuit of known resistance.

Theoretically there are a number of corrections to make, such as those which arise from the varying resistance of the junction itself, and of the leads; but the comparatively high resistance of the galvanometer renders these insignificant. Thus the resistance of the wires forming the couple was in one experiment 2·42 ohms, of the leads 0·175 ohm, and of the galvanometer 201 ohms. The part of the wires heated to a high temperature was too short to form an appreciable part of the resistance, even if its own resistance were doubled. Consequently the first correction e reduces itself to a simple temperature correction, applied to the galvanometer. This at first sight might appear to involve several corrections:—first, a correction for change c in resistance of the coil B, Fig. 5, Plate 116; second, a correction for variation r in the torsion of the suspending wire S; third, a correction for any modification m of the magnetic field of the galvanometer.

The correction for change c in resistance of the coil is easily made. The coil is of German silver, which has a temperature coefficient of 0·00038 per degree centigrade. The deflection at the melting point of gold was 16 centimetres upon the particular scale employed; hence a rise in temperature of 1° C. decreases the deflection from 16 to 15·994.

The variation r in the torsional resistance of the suspending wire was found to be quite negligible. Time readings were taken of the oscillations of the mirror, 500 consecutive oscillations being taken several times each day on different days and at different temperatures. No difference in time of oscillations greater than 0·2 second could be detected with a stop-watch. One indirect effect however was observed. The pillar of the instrument supporting the wire and coil does not appear to be made of the same material as the suspending wire itself; and as this suspending wire has some initial torsional strain, the zero of the instrument changes slightly with changes of temperature. After this was discovered, special care was taken to watch the zero.

The modification m of the field in which the coil hangs is probably very small; any alteration would be at once checked and provided for by the system of introducing known high temperatures.

The temperature as indicated by the deflection of the mirror has also to be corrected for variation f in the temperature of the cold

junctions. Obviously the pyrometer measures only the differences of temperature between the cold junction of the copper terminals and the heated junction of the thermo-couple; but by keeping the former at one temperature the indications of the pyrometer are measures of the differences between this temperature and that of the heated couple. The curve connecting the deflections with their corresponding temperatures is very nearly a straight line throughout the range of the experiments; and consequently it is legitimate to add to or subtract from the deflection an amount corresponding with the small variation of the cold junction from some normal temperature taken at 18° C. This correction and that for change in resistance of the coil of the galvanometer are applied to the observed deflection produced by the source of heat, the temperature of which was to be determined. This deflection is then compared with the deflection (also corrected) that is obtained by the introduction of known high temperatures, usually afforded by a crucible filled with pure molten gold; and the difference, multiplied by the constant obtained from the part of the calibration curve (of the particular wire) which corresponds to the range of temperature, gives the difference in degrees centigrade from the known high temperature.

If the thermo-junction be ruptured, the ends of the wires may be joined again after the removal of the defective part. Nevertheless in conducting a series of experiments it is very desirable to employ for as long as possible the same thermo-junction; and it is therefore necessary to adopt precautions with a view to its preservation. This gives rise to considerable difficulty, in view of the absolute necessity for bringing the couple into close proximity to the molten metal; and several methods of protecting the couple were adopted. Clay coverings were open to the objection of their fragility under sudden exposure to heat; and this entails the risk of spoiling a thermo-couple in the midst of an investigation. Enclosing the junction in little tubes of iron filled with silver answers very well for comparatively low temperatures; but iron alloys readily with many metals into which the tube would have to be inserted; for instance, the iron-protected junction could not be plunged into molten gold. Ultimately blocks were cut from portions of large "plumbago pots"

used in mint work, and were carefully fashioned in the lathe into small crucibles of the ordinary shape, but provided with a tube or socket extending vertically from the base up to about one-third the height of the crucible, as shown in the section, Fig. 6, Plate 116. The thermo-couple could then be inserted in the tube, which was surrounded by the molten metal. The Morgan Crucible Company have since made crucibles of this pattern specially for this research. This plan was independently devised for the purposes of the present research; it had however been anticipated by Barus,* who used a similar arrangement on a larger scale for determining the boiling points of metals. In ascertaining the point of solidification of a metal, the crucible filled with metal is withdrawn from the furnace, and placed over the thermo-junction so that the wires are near the top of the tube, but do not touch its sides. To prevent them from doing so, a cap made of sheet platinum is always kept fitted over them, and probably is specially useful in protecting the platinum wires from being contaminated with silicon and carbon, which Callendar† has already shown to increase the resistance of platinum wires; they certainly injure the wires mechanically.

Liquation of Silver-Copper Alloys.—In order to gain some evidence as to the capabilities of the appliance, it was subjected to the following tests in connection with the liquation of silver-copper alloys, that is, the separation of their more fusible constituents. This series of alloys has previously been the subject of careful experiment, and much is now known respecting them. Not the least interesting fact connected with them is the remarkable molecular re-arrangement they undergo during solidification. Levol,‡ who is the chief authority on the subject, concluded that the only homogeneous alloy contains 71·893 per cent. of silver and 28·107 per cent. of copper; and he considers it to be a definite combination

* Bulletin of the United States Geological Survey, No. 54, 1889, p. 92.

† Philosophical Transactions of the Royal Society, vol. clxxviii, 1887, p. 161.

‡ Annales de Chimie et de Physique, vol. xxxvi, 1852, p. 193; vol. xxxix, 1853, p. 163.

of the two metals having the formula $Ag_3 Cu_2$. Many years ago I also examined the behaviour of the silver-copper alloys during cooling; and the following figures and diagram, Fig. 7, Plate 116, taken from my paper,* may be given, as showing the way in which a cubical mass, 45 mm. or $1\frac{3}{4}$ inch side, will arrange itself in cooling

Alloy containing 92·5 *per cent. Silver and* 7·5 *per cent. Copper, cooled rapidly.* (*See Fig.* 7, *Plate* 116.)

Central Vertical Plane.	Percentage of Silver.	Corners.	Percentage of Silver.	Sides.	Percentage of Silver.
a	92·46	*h*	92·32	*q*	92·36
b	92·60	*i*	92·37	*r*	92·38
c	92·91	*k*	92·33	*s*	92·31
d	93·55	*l*	92·33		
e	93·10	*m*	92·39		
f	92·50	*n*	92·38		
g	92·42	*o*	92·27	Dip assay	92·51
		p	92·32		

Maximum difference, between centre *d* and corner *o*, 1·28 per cent.

rapidly. It will be evident that the silver becomes concentrated towards the centre of the mass, which is richer in silver by 1·28 per cent. than the external portions.

The results of a memorable research led Guthrie† to the conclusion that certain alloys in cooling "throw off atomically definite bodies, leaving behind a fluid mass which is not definite in composition;" so that ultimately the most fusible alloy of the series is left, which he calls the *eutectic* or most fusible alloy, and in it the "proportions between the constituent metals are not atomic proportions." Guthrie's experiments dealt only with alloys of low melting-points, such as the fusible metals; but photographic records of the rate of cooling, as measured by the platinum and platinum-rhodium thermo-couple, might be expected to show at what temperatures groups of silver-copper alloys solidify, and fall out of solution. And at the same time evidence as to the probable composition of the eutectic alloy of the series should be as readily

* Proceedings of the Royal Society, vol. xxiii, 1874–5, p. 481.

† Philosophical Magazine, vol. xvii, 1884, p. 462.

obtained by these means as it was, in the earlier experiments, by placing an ordinary mercurial thermometer in a bath of fusible metal.

Fig. 11, Plate 117, represents such a photographic record of the rate of cooling of a mass of standard silver weighing 11 oz. It will be seen that the initial temperature indicated is 1068° C., and that there is a fall to 856° C. at *b*, when the freezing of the mass as a whole begins. But before this abrupt turn in the curve takes place, there is a slight change in its direction at *a*, probably caused by a falling out of alloys rich in copper. After the abrupt break at *b* a slight upward tendency *c* shows that heat is evolved; but the curve continues to fall until another abrupt change occurs at 748° at *d*, which indicates that a second critical point has been reached. That this is attended by the evolution of heat is seen, for the spot of light remains stationary for forty seconds; and it is doubtless caused by the solidification of the eutectic alloy, that is, the most fusible alloy of the series.

Similar photographic records of the cooling of Levol's alloy $Ag_3 Cu_2$, containing 71·893 per cent. of silver, show that there is only a single break, Fig. 11, which occurs at this same temperature 748° C.; solidification throughout the mass then takes place. A record of the cooling of a mass of silver-copper, Ag Cu containing 63·029 per cent. of silver, also gives only a single break at 748° C.; but although the freezing point of the eutectic alloy is evidently close to this temperature of 748° C., it would not be safe to conclude that either $Ag_3 Cu_2$ or Ag Cu is itself the eutectic alloy; they are probably only the last alloys (in which the constituents are in simple atomic proportions) to fall out of a bath of indefinite composition. Other alloys of this series have been examined, and the curve of the one containing 60 per cent. of silver is also shown in Fig. 11. It seems to show that in a series of alloys the second point of solidification is not quite constant. The behaviour of a solidifying mass of gun-metal appears to present exactly the same characteristics; but the experiments have not as yet been concluded. It is easy in the case of alloys like fusible metal to keep the alloy melted, and to ascertain what the composition of the most fusible alloy really is,

by repeatedly straining the fluid mass from the suspended crystals through a canvass or asbestos bag. The temperature required to separate the eutectic alloy of the silver-copper series would introduce many difficulties of manipulation, though the result might ultimately be obtained.

The accompanying photographic curve, Fig. 12, Plate 118, shows the application of the photographic method to recording the evolution of heat which occurs in cooling masses of steel. The experiment was made on a piece of the same steel which had already been subjected to experiments by M. Osmond. It had the following composition:—carbon 0·160 per cent.; silicon 0·012; sulphur 0·021; phosphorus 0·029; manganese 0·110 per cent. The results of cooling it are shown by the upper curve in Fig. 12. It will be observed that, as the mass cooled down, there were, as M. Osmond had shown, two distinct evolutions of heat: one *d* occurs at 843° C. or 1549° Fahr., which is believed to mark the change of hard to soft iron, because it occurs also in iron free from carbon; and the other *f* is at 675° C. or 1247° Fahr., and is certainly due to the change in the relation between the carbon and the iron. There is probably also another slight evolution of heat *e* at 767° C. or 1413° Fahr. It is interesting to compare this curve with the one below it, obtained during the cooling of a mass of steel containing nearly 0·5 per cent. of carbon, in which there is a distinct evolution of heat at 820° C. or 1508° Fahr., and a prolonged one at 650° C. or 1202° Fahr. With reference to these curves M. Osmond himself wrote to me on 18th Dec. 1890, "the photographs are very beautiful, but, as you say, this mode of representation [by time-temperature curves] is not well adapted for showing slight evolutions of heat which occur while the cooling of the mass is slow [and is represented by the flat part of the curve]. It is certain however that the slightest prominence shown in the curve is a real one, and is not due to errors of plotting. The curve representing my steel is perfectly clear; but your specimen appears to have been well chosen for showing the two critical points."

Effect of small quantities of impurity on the freezing point of Gold.—The fundamental effect of an impurity in modifying the mechanical

properties of metals has been abundantly established; but the part played by the impurity may be twofold. It may act directly on its own account upon the mass; and, by changing its structure, may alter its mechanical properties when solid. Or, as Osmond's * work has shown, it may cause, retard, or hasten the passage of a metal in which it is hidden from its normal to an allotropic state, and may affect its properties indirectly. For the purpose of investigating these two distinct sets of phenomena, gold offers many advantages. It may be prepared in a very high degree of purity; it is not liable to contamination by oxidation; and much is already known respecting certain of its mechanical and thermal † properties as influenced by small quantities of impurity, which exert a truly astonishing influence on its strength and extensibility. Platinum would no doubt be even better; but its manipulation is attended with many difficulties. In the case of gold such difficulties can be met; and when they have been surmounted the work may be carried on with confidence, so as to prepare for the extension of the experiments to metals in ordinary use. It would appear therefore most desirable to obtain thermal evidence as to the influence of impurities on a cooling mass of gold. In what degree, for instance, is the freezing point of gold influenced by the presence of definite impurities? and is the final solidification of the mass preceded in the respective cases by a pasty stage? or does the passage from the fluid to the solid state take place rapidly? Many years ago I called attention to the remarkable lowering in the melting point of gold, produced by the presence of silicon; but the want of a suitable pyrometer has hitherto prevented my making direct experiments upon the subject.

The method of preparing gold of a high degree of purity has already been described.‡ In each experiment now to be more fully described, 132 grammes or 2,037 grains of gold were melted in one of the crucibles provided with a central tube or socket as already described, and weighing with its cover 130 grammes or 2,006 grains.

* Comptes Rendus, vol. cx, 1890, p. 346.

† Annales de Chimie et de Physique, vol. xx, 1880, p. 66.

‡ Philosophical Transactions of the Royal Society, vol. clxxix, 1888, pp. 339–349.

The initial temperature of the molten mass was high, somewhere about 1,200° C. or 2,200° Fahr.; and the durability of the thermo-junction and the constancy of its readings had therefore to be carefully tested. It was found by repeated trials that different crucibles of the same size, filled with identical weights of gold, gave closely concordant results; but it occasionally happened that the platinum wire of the couple became brittle and broke. In such cases the fractured portion was removed, and the ends were twisted together again. Throughout the course of the experiments, a crucible filled with pure gold was kept at hand, and the freezing point of the molten metal was determined from time to time as a check.

The object of the experiments was primarily to ascertain whether the influence of impurities on the metal was really tangible, that is, whether the insertion of the point of a fine stirrer of clay would indicate the existence of a pasty or gritty stage; but advantage was taken of the installation of the appliances to determine what retardation of the freezing point of gold is produced by the known elements which are added to it.

The result of Raoult's investigations on the lowering of the freezing points of solutions led him to the conclusion that one molecular proportion of any substance, dissolved in a hundred molecular proportions of any solvent whatever, lowers the freezing point of that solvent 0·62° C. or 1·12° Fahr. This had not been tested in the case of solutions of metals in metals, until Heycock and Neville* began an elaborate investigation of the subject. Their research, as far as it has at present been carried, deals first with the lowering of the freezing points of sodium and tin, produced by the addition to them of certain other metals; and second, with the molecular weights of metals when in solution. The results of their experiments when compared with the empirical laws of Coppet and Raoult may be briefly stated as follows. They are in accordance with the law "that for moderate concentration the fall in the freezing point is proportional to the

* Riemsdijk, Journal of the Chemical Society, vol. lv, 1889, p. 666; vol. lvii, 1890, pp. 376 and 656.

weight of the dissolved substance present in a constant weight of solvent." By making the assumption that the molecule of zinc or of mercury is monatomic when in solution in tin, they confirm the second law "that, when the falls produced in the same solvent by different dissolved substances are compared, it is found that a molecular weight of a dissolved substance produces the same fall whatever the substance is." But the third law, which states "that, if a constant number of molecular weights of the solvent be taken, then the fall is independent of the nature of the solvent," they found to be probably incorrect; and theoretical considerations indeed would lead us to expect this. In the case of silicon in standard gold, which has already been mentioned, a long semi-fluid stage appears to be set up; the metal may contain solidified particles, and yet be sufficiently fluid to flow readily; this phenomenon has not yet been fully investigated.

In a research of much interest, Ramsay* has determined the molecular weight of a number of metals by Raoult's vapour-pressure method: that is, he ascertained the depression of the vapour-pressure of the solvent, produced by a known weight of dissolved substance, and he finds that, although sodium behaves irregularly, yet "it would appear legitimate to infer that in solution, as a rule, the atom of a metal is identical with its molecule, as the physical properties of those metals which have been vaporised would lead us to suppose."

The experiments were conducted as follows. The gold was melted in the crucible, and its freezing point noted in two ways:—first, by recording with the aid of a chronograph the rate at which the mass cooled, the results being plotted in a curve with time and temperature as co-ordinates. The exact freezing point was then indicated by the abrupt change in the direction of the curve. Second, the freezing point was also actually observed in the following way:—the cover of the crucible had an orifice, which could be covered with a plug of charcoal, and through this orifice was inserted a fine pipe-clay rod held in the hand. A little experience with this, in touching the surface of the molten mass, enabled the

* Journal of the Chemical Society, vol. lv, 1889, p. 521. See also Tammann, Zeitschrift für physikalische Chemie, 1889, p. 441.

existence of either a pasty or a gritty stage to be detected, and the point of actual solidification to be noted; and this point was telegraphed on to the chronograph tape by a distinctive sign. The gold was then re-melted, and the impurity to be added was carefully weighed, wrapped in pure gold foil, and added to the molten mass, which was well stirred with a fine clay stirrer, and replaced in the furnace to make sure that the mass was thoroughly fluid. The crucible was placed in position over the thermo-junction, and the freezing point observed as before. Lead and bismuth exert a great influence in diminishing the tenacity and extensibility of gold; and they were therefore first selected with a view to study their action upon its freezing point. In the gold-lead series, Fig. 10, Plate 116, the full curve A is the normal line, representing the freezing of pure gold; and the dotted curves B C D were obtained as the results of successive additions of lead, B corresponding with 0·2 per cent., C with 0·4 per cent., and D with 0·8 per cent. of lead. The lowering of the freezing point was found to be proportional to the amount of lead added. No marked pasty stage was detected; and the lowering of the freezing point appears to be about 19° C. or 34° Fahr. for every atom of lead added to a hundred atoms of gold.

The calculations are as follows. The atomic theory assumes that there are as many atoms in 196 parts by weight of gold as there are in 208 parts by weight of lead. Consequently if 0·2 per cent. of lead be added to a mass of gold, there will be $0{\cdot}2 \times 196 \div 208 = 0{\cdot}19$ atom of lead per hundred atoms of gold. Dividing the observed fall of the freezing point in degrees centigrade by the number of atoms of impurity which causes it in a hundred atoms of gold, the figure known as the "atomic fall" is obtained; and this is nearly constant for any given mass of an individual metal. As soon as 0·3 per cent. of lead is present, oxidation causes a little trouble; and apparently a simple molecular action gives place to one of more complex character, the result being that the further alteration of the freezing point is not so great as it was initially.

The series with bismuth showed a very regular lowering of the temperature of the freezing point, giving an atomic fall of 17° C. or 31° Fahr. up to 2 or 3 per cent. of bismuth. Even with 19 per cent.

of bismuth there is a point well marked in the curve, showing where solidification commences. A study of these curves gives rise to a suspicion that a "trace" of impurity has an important effect upon the latent and specific heats; but until the experiments are repeated under very accurate calorimetric conditions, this point is uncertain. Bismuth probably gives a eutectic alloy of very low melting point, the pasty stage being maintained down to temperatures differing but little from that of melting lead; but the experiments have not been carried further at present. It is remarkable that a small quantity of bismuth in gold produces a lead-grey or almost purple colour of the fractured surface, which, upon burnishing, becomes at once golden yellow. This is doubtless due to the very distinct liquation that can be observed, the granules of nearly pure gold being surrounded by a brittle and impure mass.

Platinum gave an interesting series of results, which indicated an atomic fall of 17° C. or 31° Fahr. But gold is very soon saturated with platinum; apparently 0·6 per cent. is sufficient for that purpose. The first addition of platinum at once stopped the "piping" of the solidifiying mass, which is so marked a feature in very pure gold; and gave the characteristic crystalline surface which indicates the presence of platinum. An accident prevented the series from being carried beyond 1 per cent. of platinum, which amount however is sufficient to raise the freezing point again to that of pure gold.

Silicon, which has a small atomic weight, exerts a great influence on the freezing point of gold; but much difficulty was experienced in getting it to alloy with the gold. The fall produced was at the rate of 16° C. or 29° Fahr. for each atom in a hundred atoms of gold.

Manganese was also somewhat difficult to alloy; but after the union of the gold and manganese had been effected, the mass behaved in a peculiar way, indicating considerable internal changes in their mode of association near the freezing point. The bath remained quite mirror-like and limpid until the freezing point was reached; it then suddenly clouded over, and a granular mass began to form. The results were remarkable from the fact that the atomic fall was found to be only one half that obtained in most other cases; thus there is reason to conclude that manganese exists in this particular instance as a diatomic molecule.

The effect of aluminium was also studied, on account of the interest it possesses in connection with the metallurgy of iron. The gold combined with this metal with avidity, and when cold the fracture showed very marked granular structure. A study of the curve indicates that an almost chaotic state is produced in the gold by the addition of aluminium: not only is the point of initial freezing lowered, but the metal only partially solidifies during a very long range of temperature, and could easily be poured at several hundred degrees lower than the initial freezing point. This in all probability is the reason for the conflict of opinion as to the amount and nature of the change produced in the freezing point of wrought-iron by the presence of aluminium, as in the case of the well-known "mitis" castings. The long pasty stage which aluminium sets up is very deceptive, and renders it difficult to determine which is the true freezing point. Aluminium has a low atomic weight, and causes a very considerable fall in the freezing point of gold; this fall however is only one-third of that produced per atom by other impurities.

Silver occupies a remarkable position in the series. Very pure silver was used, which had been tested by Stas; but it required nearly 5 per cent. of silver to cause any appreciable lowering of the freezing point. Whether solid gold is capable of dissolving silver cannot yet be proved; but it opens an extremely interesting field for research.

Steel.—From the engineer's point of view the most interesting information which the pyrometer has as yet afforded is connected with the measurement of internal stresses in iron and steel. Osmond's work has shown that molecular changes take place in steel; and it is evident that the occurrence of these changes must be of vital importance when the metal is subjected at high temperatures to mechanical operations such as rolling or forging. The question naturally arises, do the molecular changes in the iron take place at one moment throughout the mass of metal? that is, is the rate of cooling approximately uniform throughout the mass? Or does the external portion of a hot ingot cool so much more rapidly than the centre as to allow the molecular changes in the iron, and the alterations in the relation between the carbon and the iron, to

become completed near the surface long before they take place in the interior of the mass? The experimental difficulties in the way of obtaining information upon these points have hitherto appeared to be insuperable; but the pyrometric method used in this research affords most important evidence, as a brief description of the following experiments will show.

Two thermo-junctions made from adjacent pieces off the same coils of wire, and both insulated in the ordinary way by means of pipe-clay tubes, were carefully prepared. A miniature ingot of mild steel, four inches diameter and eight inches long, shown in section in Fig. 8, Plate 116, was provided by the Director-General of Ordnance Factories; one hole 5-16ths inch diameter was drilled from the centre of one end to a depth of four inches; and another hole of the same diameter was drilled near the edge of the same end to a depth of one inch. The ingot was then heated to bright redness in a furnace; and when it had been withdrawn, the two thermo-junctions were inserted, one in each of the holes. Then by means of a special switch they were alternately connected for short but measured periods of time with the galvanometer of the photographic recording apparatus. Curves were thus obtained from *both* the thermo-junctions simultaneously, each curve being made up of short dashes. In the case of mild steel the evidence as to molecular change was but slight; but with a similar ingot of moderately hard steel the results, which are shown in Figs. 13, 14, and 15, Plates 119 to 121, are very interesting. This ingot contained 0·799 per cent. of carbon, 0·084 per cent. of silicon, and 0·412 per cent. of manganese.

In Fig. 13, Plate 119, which represents the cooling of the ingot in air, the upper curve records the cooling of the centre of the ingot, and the lower the cooling of the outer portion. The initial temperature at the centre was 1,160° C. or 2,120° Fahr. The molecular change in the iron can be detected at 880° C. or 1,616° Fahr., and the carbon change takes place at 696° C. or 1,285° Fahr. In the lower curve, representing the cooling of the circumference, the carbon change takes place no less than four minutes earlier than at the centre, and at the lower temperature of 665° C. or 1,229° Fahr., as compared with 696° C. or 1,285° Fahr. This

is a most interesting point, as Osmond has already shown that the rate of cooling has a measurable effect upon the temperatures at which molecular change occurs. The great internal strain which must be set up between the points marked A and B in the upper curve is evident when it is borne in mind that the carbon change is accompanied by a considerable alteration of volume.

In Fig. 14, Plate 120, is shown a pair of curves obtained from the same ingot when cooled by a water-spray. These present but few additional points of interest.

In the experiment represented by Fig. 15, Plate 121, the ingot was plunged, when its exterior was at a temperature of 850° C. or 1,560° Fahr., into a tank of cold water. The lower curve however, representing the rate of cooling of the outer portions of the ingot, is not strictly autographic, as it was slightly defective on the original photographic plate for temperatures below 600° C. or 1,100° Fahr. The upper curve is autographic throughout.

In all these experiments it was found that the flow of heat from the centre of such an ingot was not sufficiently rapid to prevent there being considerable variations in temperature within the mass. There can be but little question that such experiments well deserve careful attention, and in the hands of competent observers should be fruitful of results.

The Committee authorised me to secure the services of an assistant to aid me in conducting these researches. Mr. H. C. Jenkins, Whitworth Scholar and Associate of the Royal School of Mines, was accordingly chosen, and has proved himself to be a patient and careful experimenter, and has shown that he possesses manipulative skill of a high order.

Discussion.

Professor Roberts-Austen exhibited the pyrometer actually employed in this research, Fig. 1, Plate 115, but taken out of the case in which the sliding sensitized plate was made to travel for tracing the photographic curve. He showed the action of the instrument during the heating and cooling of a small piece of iron, the beam of light reflected from the galvanometer mirror being seen to pause in its movement in either direction as soon as the temperature was reached of 850° C. or 1,560° Fahr., at which the thermal change took place, indicating the corresponding transformation in the nature of the iron.

He explained that while, according to the "periodic law," as originally expressed, "the properties of the elements are a periodic function of their atomic weights," it seemed easier, with regard to the mechanical properties of metals, to trace the influence of their atomic volumes than of their atomic weights: the atomic volume of an element being found by dividing its atomic weight by its specific gravity. A singular fact then came out. It was necessary first of all to find some particular metal on which the effect of traces of impurity could best be tried; and for many reasons gold appeared to be the most favourable for such an investigation. Copper might be added to gold, and would increase its tenacity; but the addition of a trace of lead or bismuth to gold resulted in the production of a mass as brittle as loaf sugar; and by adding to gold a constant quantity, namely 0·2 per cent., of various impurities, the singular fact was discovered that the tenacity was rapidly affected in inverse proportion to the relative volume of the added impurity: that is, as plotted in the diagram, Fig. 16, Plate 122, the elements which had atomic volumes larger than that of gold tended to diminish its tenacity, while those which had smaller volumes tended to increase it. Therefore when an element was added which had a much larger atomic volume, as in the case of bismuth, the gold so alloyed had practically no tenacity at all. It was this singular fact which had led Dr. Anderson to propose to the Council of the Institution of Mechanical Engineers that a committee should be appointed to ascertain how far the same result followed generally

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with the metals most used in mechanical engineering, when traces of other elements were added to them; and he would take this opportunity of recording his gratitude not only to Dr. Anderson, but also to the Institution, for the welcome encouragement offered to himself as a metallurgist to bring before them a matter so important to their interests.

The need for applying such investigations to iron became daily more and more evident indeed; but the questions presented themselves at the outset—did iron always behave itself properly? was it always in the normal state in which engineers mostly knew it? or might it behave like many other elements, and pass from a normal state to an allotropic? Many elements were known to possess such a dual state. Carbon might appear in its graphite form, or in its diamond form; silicon in its graphitic, or in its diamond; phosphorus in its red or its yellow modification. Sulphur was most familiarly known in its crystalline and brittle variety, of which a specimen was here exhibited; but if this ordinary sulphur was melted and poured into water at a certain temperature, though it underwent no other change and was still absolutely pure sulphur, it became a plastic substance, of which a specimen was also shown, resembling india-rubber; and if again this plastic sulphur was heated to a temperature of about 90° C. or 190° Fahr., it suddenly evolved heat and passed back into the original crystalline state. Nothing had been changed in its composition, no other ingredient had been added; the transformation was simply a passage from one state to the other. He believed, though he was not absolutely sure, that if in its plastic state it was stretched beyond its limit of elasticity it was thereby made to pass into the crystalline variety; experiments which Professor Kennedy and himself had been making upon it in that way during the reading of the report had gone far to convince them that this was really the case, and if so it was a very curious fact. What he wanted now to insist upon was that here was one and the same substance existing in two such widely different states. Was iron capable of behaving in this way? Was it capable of taking advantage of any condition in which it might find itself, and of rearranging the atoms of its molecules, and so passing from

one state to another? Many observers, beginning with Joule, thought that this was the case; but of all experimenters M. F. Osmond of Paris, whose name recurred so often in the report just read, had perhaps made the most definite advance in this direction. Osmond had shown that, if a piece of iron were allowed to cool in contact with Le Chatelier's thermo-electric pyrometer, as it cooled down from a bright red heat of over 1,000° C. or 1,800° Fahr. to a temperature of 850° C. or 1,560° Fahr., the march of the spot of light indicating the cooling continued perfectly regular and uniform; but as soon as ever the temperature of 850° C. was reached, the iron showed evidences of some change: for a few seconds heat was evolved, and the spot of light remained stationary. Osmond stated that in its red-hot condition iron was really in the β or hard state. Owing to the temperature indeed, its molecules were only united loosely, and therefore it was true the red-hot mass as a whole was soft; but the individual molecules, if they could really be got at or could be resolved into their atoms, would be found to be hard. As soon however as the iron cooled down to the temperature of 850° C. there was an evolution of heat, just exactly as there was when the plastic variety of sulphur passed into the crystalline; and Osmond urged that at this temperature the iron became changed into the α or soft state. Now supposing that, instead of pure iron, the cooling were observed of carburized iron, that is, of steel; then it was found that not only was there the one distinct evolution of heat, which Osmond believed to be due to the passage of the iron from the hard state to the soft, but there was also another distinct evolution of heat at about 675° C. or 1,247° Fahr., which he was satisfied was due to the change in the relation between the carbon and the iron.

The whole question as to the allotropy of iron turned on such evidence as it might be possible to collect of the passage of *pure* iron itself, free from any other ingredient, from one state to another, as indicated by the evolution of heat, which was widely admitted to be the main test of the passage from one state of aggregation to another. Osmond thought he had satisfied himself upon this point by finding that electro-deposited iron showed such an

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evolution of heat while it was cooling down. Now it was known that electro-deposited iron was hard; and its hardness might be due either to its structure, arising from the method by which it was deposited, or to the fact that it retained within itself a large volume of occluded hydrogen. By means of the pyrometer he had tried to get a step further. A little piece of electro-deposited iron had been heated in a vacuum by the arrangement sketched in Fig. 17, Plate 122; it was enclosed in a porcelain tube P, and the two wires from the pyrometer were passed in through the one end to the iron I, and a tube passing through the other end was attached to a Sprengel mercurial pump, whereby the porcelain tube was rendered perfectly vacuous, so that the iron could be heated in a vacuum by raising to bright redness the portion of the tube where the iron was situated. As the temperature rose, the occluded hydrogen gas began to come off, and at the temperature of 200° C. it was freely evolved and soon exhausted itself; and then there was a perfect vacuum in which the heating of the iron could be continued. The usual photographic record of the heating or the cooling of such a piece of iron in vacuo could therefore be readily obtained. Moreover it was easy, by obscuring the source of light for a moment, to obtain a break or indication in the curve at the points where the evolution of gas began and ended. The evolution ceased, and the perfection of the vacuum was restored, before the iron reached a temperature of 400° C. Any change thenceforth observed must be due to a change either in the iron itself or in some impurity contained in it; if the iron was really pure, it must be due to the iron itself, and to nothing else. As soon as the temperature reached 850° C., there was a distinct absorption of heat. Barrett had shown that recalescence, or the evolution of heat during cooling, was a reversible property: that is, during the heating of the same substance there was an absorption of heat, or a certain quantity of heat became latent, at the same temperature at which the evolution had occurred during cooling. The autographic curve drawn during the heating was shown in Fig. 18, Plate 122, and formed a branch of the investigation which had been added since the report was written. Proceeding still further, the temperature was raised to

900° C.; and then, as the iron was allowed to cool, the converse occurrence took place at 850° C., namely evolution of heat, due to change in the iron. Thus electro-deposited iron deprived of its hydrogen exhibited the reversible property of recalescence. The only question that remained was, did the iron contain carbon? The experiment by Osmond proved to be not absolutely conclusive, as the electro-deposited iron had in that case been found to contain 0·08 per cent. of carbon. Though a mere trace, it seemed far from certain whether even so minute a quantity of carbon might not be sufficient to produce mischief. A particular piece of electro-deposited iron, which he himself had subjected to the foregoing treatment in a vacuum, had therefore been analysed for him by one of the most competent analysts he knew, Mr. Edward Riley; by whom the presence of carbon had indeed been detected, but to the extent of only 0·007 per cent., which had possibly come from a speck of dust. However, if the objection to the view that iron could assume an allotropic state was thought to be supported by the detection of so minute a proportion of carbon, he was afraid he had at present no answer.

There was one other piece of evidence to which he wished to call attention, as to the possibility of the existence of iron in the β or hard state. When a mass of iron or steel was being heated, as soon as it reached a certain temperature, varying according to its composition between 600° and 700° C., or 1,100° and 1,300° Fahr., it ceased to be magnetic; it was well known that red-hot iron was not magnetic, and the contention was that in red-hot iron the metal existed in the β or hard form. In one of the most remarkable metallurgical investigations of the past few years, Mr. Hadfield had dealt with a series of alloys of iron with manganese, and had shown what remarkable properties they possessed. One fact bearing upon the present research was that, if iron contained more than 7 per cent. of manganese, it did not show in cooling the evolution of heat characteristic of other varieties of iron. Then, according to the theory advocated by M. Osmond and himself, such a material should be hard, however slowly it was cooled; and such proved to be the case. Further, if the iron was present in the β or hard form, the mass should not

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be magnetic in the cold; and it was not magnetic, as was proved by experiment. In this connection he thought the experiments which had been made on the cooling of the miniature ingot of mild steel (page 565) really deserved far more careful attention than it had yet been possible to give them. They marked indeed only the first breaking of the ground for a long investigation. M. Osmond had written to him within the last few days, stating that he considered this to be one of the most important directions in which investigation could possibly be extended.

At one of the Research Committee meetings the President had asked that attention should be given to the alloys of copper, with special reference to the quality of copper used for the fire-boxes of locomotives at the present time. He had carefully sought for evidence of any allotropic change being produced in copper by heating and cooling, but had not been able to find it. He did find however that the presence of only one per cent. of arsenic rendered copper much stronger, not only at ordinary temperatures, but also at temperatures to which copper used for locomotive fire-boxes might be subjected. When this portion of the investigation had been further followed, he hoped to have a more complete answer to the question raised by the President.

Anyone who had to conduct experimental investigations would know how much depended upon the nature of the assistance he could obtain; and he was glad therefore to refer to the efficient aid he had received from Mr. Jenkins, who had already manifested his qualifications as a metallurgist.

Dr. William Anderson, Vice-President, and Chairman of the Alloys Research Committee of the Institution, noticed a contrast between the paper on boiler construction, read on the preceding evening, and the report to which they had just listened. The former contained scarcely a particle of theory: whereas the report now presented was naturally full of theory, but theory of a most important kind, though possibly the practical bearing of the research which Professor Roberts-Austen had been conducting with so much skill might not be quite so apparent at first sight as it would

certainly become later on. Too much stress could not be laid on the discovery, if it might so be called, of the Le Chatelier pyrometer. In the first place it was a means of ascertaining very high temperatures with absolute certainty. The calibration curve in Fig. 2, Plate 115, showed what reliance might be placed upon it; and the extreme smallness of the twisted junction of the two wires, Figs. 4 and 8, Plate 116, enabled them to be inserted with great ease in any substance, of which it was desired to ascertain the temperature. In the next place this discovery gave even now, and he could not help thinking it would do so still more in the future, a wonderful power of ascertaining the quality of a mass of steel in every part from one end to the other. Hitherto, in the case of large forgings, specimens might indeed be got from the two ends, and be tested mechanically. But these left in absolute darkness the quality of the intermediate portions of the mass. Of course one of the causes of the variation in the different parts of a steel forging was liquation, that is, alteration in the chemical composition of the mass by the separation of its more fusible constituents: in consequence of which the nature of the two ends and of the middle portion might not necessarily be the same; and if it was not the same, the metal would behave differently under the treatment to which the whole forging was subjected. In the case of gun steel especially, which assumed the form of long tubes and hoops—the inner tubes of some of the larger guns being nearly 50 feet long, and some of the hoops 12 or 14 feet long, 4 feet diameter, and 6 inches thick — the ends could be tested, but the middle had to be taken for granted. Now however, with the aid of this pyrometer, by taking the mere shavings that were turned out in boring or in rifling, and heating them and then letting them cool and describe autographically their own curves of cooling, it was almost certain, if the curves described by the cooling of shavings taken from every part of the forging were identical, that the composition of the forging must be everywhere the same. When more came to be known about this mode of testing, he thought that it would be possible to tell whether the physical condition of the forging was the same throughout.

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Molecular changes took place in steel, in consequence of its being in various states of tension. Just as Professor Roberts-Austen had indicated in the case of sulphur, which from its amorphous or plastic condition could by stretching be brought back to the crystalline form, so steel under severe tension undoubtedly altered its composition; and this being the case, it seemed probable that, if specimens taken from the steel were subjected to the process of cooling and of tracing their curves of cooling, the autographic curves would indicate whether there was any change, and whether there was any difference in the quality of the steel in various portions of the mass. When a change was thus indicated, of course attention would be drawn to the matter, and the effects of the change counteracted by proper treatment. For instance, forgings which were made at several heats, and were consequently in an unequal state from being partly hot and partly cold, if re-heated and properly annealed afterwards might be restored to a uniform condition throughout. The result of the researches which the Institution had started he was in great hopes would be to give a practical power of determining the internal state of the material, which would be of the utmost possible value, especially now that such enormous masses were beginning to be dealt with. The Institution he hoped would persevere with the work; it would take a long time, and the absolute results might be long of attainment; but they would certainly be reached at last.

Mr. Robert A. Hadfield, as a member of the Alloys Research Committee, considered they had been exceedingly fortunate in getting such an able and energetic worker as Professor Roberts-Austen to take up the preliminary scientific investigations of this important subject. Having himself made probably about as many experiments as any one else in this special field of research, he knew full well how great a want there was of helpers working on scientific lines like Professor Roberts-Austen, whose excellent address at the recent Cardiff meeting of the British Association upon the present state of metallurgical science was most acceptable to all interested in keeping up to date their acquaintance with metallurgical matters. In the

present discussion he hoped something would be heard from Mr. Howe of Boston, Massachusetts, whom he was sure all would be glad to see and welcome, not only on account of his own valuable treatise on the metallurgy of steel, but also as one of the hosts who last year in America had so handsomely entertained among the members of the Iron and Steel Institute many who were members also of this Institution. Such helpers were wanted to collate and arrange the results arrived at in the work of practical men, who amidst the engagements of their ordinary business, whilst able perhaps to produce valuable alloys, had not the time necessary to complete the investigation and organization of their own results.

In the report now presented by Professor Roberts-Austen there seemed to him to be certain anomalies, to which he desired in no captious spirit to draw attention, in order that some of the points raised might undergo further and fuller examination. With reference firstly to the two columns of foreign elements given in page 544 as affecting the properties of iron, he thought some modification was required in their classification, in order to be in agreement with the facts known as to the physical qualities of alloys of iron with these elements. His own attention having been devoted to alloys of iron alone, a further statement he thought might advantageously be added to the report, giving roughly the general characteristics, so far as known, of the alloys produced with these elements. To take one case, a considerable number of experiments had convinced him that, notwithstanding the atomic volume of copper being 7·1, while that of iron was 7·2, it ought not to be placed in column I along with carbon, boron, nickel, and manganese, as producing similar effects. Its effects totally differed, and he had not found any points of resemblance. This opinion had been confirmed by correspondence with M. Brustlein, who had worked on such alloys of iron. Copper should probably be classed with sulphur, phosphorus, and arsenic, and perhaps with silicon and aluminium. Apparently it did not confer hardness, and did not delay the change of β or hard iron, if such existed, into α or soft iron: judging at any rate from those alloys of copper and iron that he had to do with.

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Again, in a recent interesting communication to the French Society of Chemistry (Bulletin 1891, pages 840–3) respecting the allotropic transformations of metals, M. Le Chatelier said that the results of a considerable number of his experiments pointed to the existence of only a limited number of allotropic changes; and that therefore the variability in the physical properties of metals could not be explained by their existence in an unlimited number of slightly different isomeric states. M. Le Chatelier considered that molecular or crystalline transformations were due rather to changes in internal structure—that is, in the forms and sizes of the crystals or grains of metals in juxtaposition, and also in the mode of distribution of the impurities—than to changes in chemical character. In other words the changes that occurred were of a structural nature, and were produced by physical treatment, as distinguished from chemical action.

The following was an approximate classification which he had attempted in the light of experiments thus far made with alloys of iron that had come under his own observation; it was simply approximate, and was not drawn up as anything more than a suggestion with a view of further consideration.

Class 1. Carbon.
„ 2. Nickel, and Manganese.
„ 3. Chromium, and Tungsten.
„ 4. { A. Aluminium, and Silicon.
{ B. Sulphur, Phosphorus, Arsenic, and Copper.
Not yet classed—Lead, Tin, Cobalt, Bismuth, and Cadmium.

In class 1 he had placed carbon by itself. Neither experiment nor theory could get away from the fact that carbon alone produced "water-quenched hardness" in steel: that is, it alone conferred upon iron the property of becoming hard when water-quenched, and of acquiring such a degree of hardness as would enable it to scratch glass and to form the cutting edge of tools. He was informed by Professor Roberts-Austen that boron would do the same; but not having himself seen proof of this yet, he could not offer any positive statement of his own on this point. Samples of iron alloys which had been referred to by M. Osmond as containing boron were of so

small a size that he thought it would hardly be safe to generalize from them; and he should like to see larger pieces made and tested. The hardness in "self-hardening" steel was equally due to carbon; and makers of such steels could confirm the statement that these steels could not be self-hardening without a large percentage of carbon being present in them. In analyses of self-hardening steel that had come under his own observation there had always been a large proportion of carbon present. The hardness due to carbon was alike produced, whether the carbon was added or alloyed by itself with iron, or whether it was present in the iron along with other elements, such as chromium, a hard metal, or aluminium, a soft metal. As an example and a proof of the latter point, he had obtained good cutting tools with an alloy containing 97 per cent. iron, 2 per cent. aluminium, and 1 per cent. carbon: the softening effect of the 2 per cent. of aluminium being apparently masked by the presence of the 1 per cent. of carbon. Another special characteristic also possessed by carbon was that in small quantities it produced powerful effects, as already pointed out in Professor Roberts-Austen's report. For instance, as little as 0·05 per cent. difference from a certain standard produced steel unsuitable for the particular purpose in view. This characteristic certainly did not apply to many others of the elements that were used for alloying with iron. With some of these a difference might occur of six or eight times as much as the above, with but little change in the physical properties of the alloy.

In class 2 he would place nickel and manganese. These were elements which when added in sufficient quantities strongly stiffened iron, but did not confer the property of water-quenched hardness. Their effect most nearly approached, whilst greatly differing from, that of carbon; and they might also be termed hardeners, though of less intensity; but in no case did they give water-quenched hardness. In other respects however these two metals did not both of them produce by any means the same results. Steel with 3 per cent. of manganese was comparatively brittle in its forged state, while 3 per cent. of nickel gave a tough material. Then with increasing quantities of the latter, after exceeding 9 per cent. there was n

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development of the extraordinary strength noticed with manganese steel.

In class 3 he placed chromium and tungsten. These elements stiffened iron, but acted much less powerfully than those in class 2. They also did not confer the property of water-quenched hardness. For instance, in chromium steel, should carbon also be present, the chromium then acted powerfully in retaining the carbon in or combined with the iron as "hardening carbon." Steel containing 2 per cent. of chromium, and in which the carbon was not more than 0·12 per cent., would not harden even if water-quenched at a white heat. As soon as the carbon increased, then the hardening properties also increased. A 2 per cent. chromium steel with say 1 per cent. of carbon would harden more readily and to a greater depth, as compared with steel containing the same percentage of carbon only, and devoid of chromium. Only recently he had obtained a sample of steel containing nearly 15 per cent. of chromium, which could be forged; but he would not advise yet any attempt at such a mixture, because the forging could not be done readily. The remarkable toughness of certain kinds of special chromium steel, such as was produced by his own firm, had been shown in a trial of one of their 6-inch armour-piercing shells, made with special large core, which had penetrated a compound plate of a thickness equal to the calibre of the projectile, and had been found uninjured nearly a mile and a quarter on the other side of the plate. In another case one of their 6-inch shells of ordinary armour-piercing pattern, and of similar quality, had been fired unbroken through two separate compound plates, each 9 inches thick; it had thus punched through 18 inches of compound plate, and had still remained uninjured. When fired a third time against a specially prepared compound plate, made on the Ellis-Tressider plan by Messrs. John Brown and Co., it had met its fate; but it had taken three plates to beat one projectile. The peculiar fact in connection with this kind of steel was that chromium, whilst itself probably a very hard metal—he said probably, because he had never been able to obtain a sample of pure chromium—would yet not produce in the absence of carbon any apparent increase in the hardness of the iron with which it was alloyed, at any rate up to

3 or 4 per cent. This fact was so far in confirmation of the position assigned to chromium in the report, where it was placed in column II (page 544) among the elements tending to keep iron soft; and he was glad to call Professor Roberts-Austen's attention to it for what it might be worth.

In class 4 he would include aluminium, silicon, sulphur, phosphorus, arsenic, and copper. Whilst agreeing in their general properties of not conferring hardness upon iron, these six might preferably be separated into two groups, A and B, group A comprising aluminium and silicon, and group B the four others. Though aluminium was a metal and silicon a metalloid, these two certainly agreed together remarkably in many of the effects they produced, though not in all. They did not act so powerfully in destroying malleability and toughness as the four others forming group B; but as soon as they exceeded say 3 per cent. the resulting alloys of iron possessed similar qualities to those imparted by the four in group B. The alloys of iron with aluminium and with silicon did not possess much commercial value, though he had obtained several remarkable results with the metalloid silicon up to as high as 2 or even 2½ per cent. The proximity in the atomic volumes of aluminium 10·6 and silicon 11·2 was worthy of note, seeing the similar results they produced when alloyed with iron.

In group B of class 4, sulphur, arsenic, and copper, when present in but small quantities, acted similarly in destroying malleability and ductility either in hot or in cold iron. Phosphorus also produced a somewhat similar effect, but might be present in larger quantities before red-shortness occurred; it caused serious brittleness in cold iron, as was well known, at any rate as regarded steel. All the above alloys, even with small percentages, were soft, brittle, and of little value. They differed from the alloys of group A in several respects.

As to iron alloyed with lead and tin, his own experiments had not been very successful. With lead it seemed impracticable to get a true alloy or combination; in fact the whole of the lead added had been found at the bottom of a steel ingot 2½ inches square, not alloyed at all and apparently unchanged. It seemed to him a rather

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remarkable circumstance for a metal having such a low melting point as lead to be found apparently unchanged at the bottom of an ingot of another metal whose melting point was ten or twelve times higher.

Some experiments had been made with cobalt. When alloying $1\frac{1}{2}$ per cent. he had found the iron forged well, but did not possess hardness. Bismuth had been tried, but the experiments were yet incomplete. The same remark applied to cadmium; if the results with it should turn out to be of any interest, he should be glad to communicate them to Professor Roberts-Austen, who had told him that he thought results of special interest might be obtained with this metal. As gold and silver were at present so scarce in steel works, nothing had been done in the direction of alloying iron with them. Faraday was reported to have experimented with silver steel, and a material bearing this name had been made in Sheffield; but he need hardly say such steel contained no silver.

Though necessarily rough and approximate, he thought that the foregoing classification, based upon the results obtained from the alloys produced, might be borne in mind before adopting as definite a classification such as that indicated in the report. The work of the Research Committee would be received with much interest by those concerned in metallurgical matters. It was therefore of the greatest importance that the theory so ably advocated by M. Osmond and also by Professor Roberts-Austen, and having so much in it that was attractive, should be most carefully verified.

With regard to pyrometers, too much could not be said in praise of the work done by Professor Roberts-Austen, who had now given a most interesting and valuable result of his labour, much of which would be of excellent service in practical working. At present there was one drawback with the pyrometer described in the report, when it was applied to determine temperatures of metals with high melting points, arising from the fact that the platinum-rhodium wires, when immersed say in molten steel, became brittle, and it was hardly possible to get more than one reading, and even then of doubtful accuracy. On this point perhaps Mr. Howe would give his opinion, as he had made considerable use of the pyrometer. If some method

could be devised of getting over this difficulty, he thought the instrument would really be a practical one and of great service. After the great amount of trouble taken by Dr. Anderson and Professor Roberts-Austen, it would have been most acceptable if the cooling diagrams from the samples tested of commercial steel had happily afforded more definite results; he trusted however that further experiments would be made. Without doubt much was to be gained by correct observation of the cooling curves, on the excellent method devised by Professor Roberts-Austen, to whom were due special thanks for the great amount of time and thought he had devoted to this investigation. From his present report it was evident that this interesting subject offered great scope for research, if systematically carried out; and he believed that discoveries were yet to be made which would prove of the utmost value to the future progress of mechanical engineering.

Mr. Henry M. Howe, Boston, Massachusetts, thought the theory was certainly most attractive that the effect produced in a metal by impurities or foreign ingredients was a function of their atomic volume. As he understood from a former paper by Professor Roberts-Austen, not only the tenacity but also the melting point should be a function of the atomic volume. That is, the effect produced on the melting point as well as on the tenacity of a metal by slight additions of foreign elements was a simple function of the atomic volume of those elements. In the case of iron, the effect of an addition of carbon was unquestionably to lower its melting point. On the new theory therefore, should not the addition of a small quantity of phosphorus, coming as this element did at the other end of the scale of atomic volumes in page 544, raise the melting point? But such evidence as at present existed, he thought, showed that phosphorus did not tend to raise the melting point of iron. There might be some way of explaining this; but at any rate, looking at the effect in general of foreign substances on iron, he thought that according to present knowledge copper and carbon could not readily be classed together in the same group. The position taken by M. Osmond which attracted the most notice and

(Mr. Henry M. Howe.)
opposition seemed to him not to be that there was an allotropic change in iron during cooling: this he thought he was prepared to admit, for the fact had long ceased to be questioned that iron suddenly lost its magnetism and suddenly regained it, not gradually, but with a leap at a critical temperature. There was no reason he thought to suspect that it had anything to do with the presence of carbon, or of anything but iron. But M. Osmond went a little further, and maintained that the hardening of iron on sudden cooling was not due to any change or difference in the condition of the carbon, as had been believed; but was due to the allotropic change in the condition of the iron itself; and apart from all his experimental skill, it had to be seen whether any evidence had been offered by him which supported his view.

The Le Chatelier pyrometer seemed to him to be one of the greatest boons that metallurgists had ever received, enabling them to measure high temperatures, even up to whiteness, with great convenience, rapidity, and accuracy. The accuracy indeed was astonishing. While not able yet to speak positively, his experience led him to hope that comparative results might under favourable conditions be got with an error of not over 2° C. or 4° Fahr.; and absolute results with an error of not over 10° C. or 18° Fahr., or perhaps even not over half as much. Careful manipulation by skilful hands was of course required for such a degree of accuracy; but even with the rougher handling which might be looked for in industrial establishments he thought there was no reason why the error should exceed 20° or at most 30° C., or say 40° to 50° Fahr., even with such high temperatures. As to rapidity, this was one of the greatest merits of the instrument. It might be illustrated by a particular case. Supposing that the temperature had to be observed simply of some one point or object, then of course absolutely continuous observations could be obtained if desired: so that the rapidity was absolute, the time taken between the observations being infinitesimal. But supposing it were wished to control the temperature of say twenty heating furnaces: then all that had to be done was simply to embed permanently in the brickwork of each furnace a thermo-electrical couple, from which a wire was led

to a switch-board in connection with a single galvanometer. By means of the switch-board the galvanometer could then be connected with one of the furnaces after another, or any one at will; and without any great hurry he saw no reason why the temperatures should not be determined of at least five furnaces in a minute. Having himself used the galvanometer under like conditions, if he remembered aright his observations had been even more rapid than this. Not more than eight seconds he thought were required to make any one observation, switching from one thermo-junction to another. The United States were now arming their coasts with large mortars, or vertical guns, cast on the Rodman principle round a water core, which purposely induced a severe stress in the steel in cooling. It was important to study the difference between the rate of cooling on the outside of the gun and in the bore; but hitherto there had been no ready means of ascertaining or controlling the rate of cooling on the outside of the gun. The rate of cooling in the bore could be got readily from observing the heating of the water; but now, in an investigation which he should take up on his return, it was intended to embed in the mould in which the gun was cast a series of thermo-electrical couples, so as to determine at very short intervals the temperature of a great number of points on the outside of the gun as it was cooling. Thence later would of course be ascertained the relation between the rate of cooling on the outside and in the bore, and the consequent stress in the gun. Such a series of observations seemed to resemble those made by Professor Roberts-Austen on the cooling of the outside and inside of ingots, as described in the report (page 565); and he fully agreed with him as to the importance of this field for research.

Professor J. O. Arnold, Sheffield, questioned whether the plan thus far pursued in this research, of which the present report was the introduction, did not entail a great waste of precious labour, with small prospect of any good result, at any rate in connection with iron and steel. Such comparatively simple substances as gold and lead seemed to him not likely to furnish any useful analogies for investigating so marvellously complex a substance as steel, which he

(Professor J. O. Arnold.)
considered to be far more important for engineers to study; and however fascinating might be the theories presented in the report, steel research was in his opinion a field of too national an importance to be used lightly as a cantering ground for the hobbies of periodicity and allotropy. The report appeared to him to be really an abridgment of M. Osmond's paper on the critical points of iron and steel, read before the Iron and Steel Institute (Journal 1890, No. I, page 38); and Professor Roberts-Austen appeared to assume a responsibility for the whole of M. Osmond's theory, much of which the speaker believed to be untenable. It might be well to point out, for the information of those who had not had an opportunity of seeing M. Osmond's own diagrams, that the prominence therein given to the points of recalescence during the cooling of a piece of steel was represented in Professor Roberts-Austen's diagram, Fig. 12, Plate 118, by nothing greater than the three tiny ledges at *d*, *e*, and *f*, in the autographic curve obtained from another piece of the same steel (page 558). Such minute deviations from the smoothness of the rest of the fair curve, drawn by the admirable photographic recorder, were hardly sufficient in his opinion to be taken as an indication of so important a change as would be that of hard into soft iron.

It was somewhat startling to metallurgists to find that chromium, silicon, and tungsten were classed in page 544 among elements which softened steel; but a little further down in the same page their softening action was qualified by the proviso, "did not their individual properties, or those of their compounds, mask this natural consequence of their presence." Such a qualification seemed to him to deprive the classification of all value, and to lead nowhere. Engineers ought to be told what were the properties of alloys of these various elements with iron and steel, if any use was to be made of them.

Hardness had been several times mentioned in the report, and also in the original paper by M. Osmond; but the fact seemed to have been ignored that there were different kinds of hardness, such as abrasion hardness and brittle hardness. A steel which was quite soft to the drill or the turning tool might nevertheless be

quite brittle under the hammer; and the hardness which rendered it brittle was a different kind of hardness from that of a turning tool. Annealing was defined in the original paper by M. Osmond as rendering iron soft and malleable by slow cooling. But annealing as carried out in M. Osmond's experiments was not annealing at all, in the proper sense in which the term was used by engineers and steelmakers. If a steel casting in a dry sand mould were left in its mould for fifteen hours, it cooled from fluidity to (say) a milk-warm heat. It was slowly cooled, and according to M. Osmond's idea it had been annealed. But a casting of average hardness so treated would be very brittle under the hammer. If however immediately after being cast it was placed in an annealing furnace, and was maintained at a fair red heat for as much as seventy hours, and was then allowed to cool gradually, the effect of such long annealing was that it became possessed of great toughness. These different states of steel appeared to him not to have been taken into account by either M. Osmond or Professor Roberts-Austen, yet they were of the utmost practical importance. In connection with M. Osmond's theory of hard and soft iron, it was represented in the report (page 558) that the point *d* in Fig. 12, Plate 118, probably marked the change from hard to soft iron in the mild steel containing 0·16 per cent. of carbon. It seemed to be believed that this very small perturbation or halt in the autographic record marked what would really be a gigantic internal convulsion, a complete change of hard iron to soft iron: that is to say, that iron when it was heated was in the hard state, and on cooling, if the steel were soft, it passed into the soft state. Moreover the theory was that carbon had an influence upon the extent of this change, and that in a steel low in carbon the iron passed almost entirely into the soft state in cooling, while in a steel high in carbon the carbon retarded the passage of the iron from the hard to the soft state. Yet this very diagram, Fig. 12, Plate 118, seemed to him to furnish evidence against such a theory altogether. If the first pause at *d* marked the change from the hard to the soft state of iron, it would be expected that in a mild steel the halt would be much more marked, because the change would be so much more complete; and

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that in a steel high in carbon, as the change was somewhat retarded by the carbon, the pause would be less marked. But as a matter of fact it would be observed that the lower curve in Fig. 12, drawn by the harder steel, presented a rather greater perturbation at the temperature *d*, where the iron was supposed to be passing from the hard into the soft state.

For some thirty years past Dr. Clifton Sorby of Sheffield had been making some remarkable researches into the microscopic structure of steel; and his results were not theories based on the slow or fast movement of a beam of light, but must be regarded as actual facts. The latest research which he had laid before the Iron and Steel Institute (Journal 1887, No. I, page 255) showed that steel was one of the most remarkable bodies in the world, either artificial or natural. In steel, just within the range of microscopic vision, was found a remarkable compound structure, called by Dr. Sorby the "pearly constituent," consisting of alternating laminæ of unequal thickness and of different composition. As far as his observations had gone, they had tended to confirm the theory that the thicker laminæ were pure iron free from carbon, and the thinner ones were carbide of iron. The thickness of the thinner laminæ was about 1-80,000th of an inch, and of the thicker about 1-40,000th of an inch. And in all the specimens he had tried of true steels, when properly prepared and magnified about 700 diameters under the microscope, Dr. Sorby had found that there constantly cropped up this remarkable structure. There was no doubt whatever that the changes in the structure of steel on hardening had an enormous influence upon its physical properties; and a reference to Dr. Sorby's microscopic researches on this subject, which he had himself almost entirely confirmed by a laborious investigation, seemed to him to be absolutely necessary in the discussion of the report now presented.

Turning to the really valuable work which had been done in this research, he was glad to call attention to the fact that, while M. Osmond had reduced into definite form the crude theories of recalescence which had been in existence for some time, and had shown certainly within fairly accurate limits the temperatures at

which recalescence really took place, Professor Roberts-Austen had now confirmed these temperatures by his autographic curves. The lower curve in Fig. 12, Plate 118, and the upper in Fig. 13, Plate 119, showed a great evolution of heat at a temperature a little below 700° C. or 1,300° Fahr., which he himself thoroughly believed in as marking a change in the carbon. By the verification of this recalescence, coupled with the results of the microscopical research, he had arrived at the conclusion that, when steel was heated, the whole of the carbon was dissolved in the iron in some form; but on cooling, the actual fact was that the steel became separated into the alternating plates of pure iron and carbide of iron. On annealing, the constituents of the plates became more segregated, and the steel was softer. The present research he therefore considered, in order to be of practical value, should certainly be correlated with microscopical research.

A feature in the present report, which he considered almost as important as Le Chatelier's pyrometer itself, was the autographic recorder; and its admirable adaptation by Professor Roberts-Austen to the pyrometer would render this instrument he believed a boon to metallurgists and engineers. On the whole he thought that this method of observation, devised by M. Osmond and Professor Roberts-Austen, must rank as one of the means by which all samples of steel used in researches must in future be examined.

In the further prosecution of this research, what he wished particularly to recommend was a careful system of extensive correlation. The examination of the steel should comprise its chemical composition, its mechanical properties under varying conditions, whether annealed or unannealed or hardened, its microscopical features, and its characteristics in respect of recalescence. If this was done—and as far as he knew there was no insuperable difficulty in the way of doing it—then scientific metallurgical research would become a practical reality to engineers; and would result in good sound work, such as better material for rails or for bridges or for shop tools. This was the direction in which he considered that all research into iron and steel should be pursued.

Mr. Charles E. Stromeyer had recently compiled the accompanying table, which might be of interest in connection with this discussion, for showing generally the influences of the various impurities in mild steel. These data he had collected from papers

Influence of Impurities
on some of the Properties of Mild Steel.

Element constituting Impurity.	Tenacity.	Elongation.	Resistance to Impact.	Pliability.			Welding.	Hardening.	Corroding.
				Cold.	Red Hot.	White Hot.			
Carbon . . .	+	−	−	−		−	−	+	−
Silicon . . .	+	−	−		−	− ?	0	+	
Arsenic . . .	+	−	−	−		0		−	
Phosphorus . .	+	−	−	−	0	−			
Sulphur . . .	0	0		0	−	0	−		
Copper . . .	+	−			−	−	0 ?		
Manganese .	+	+	+		+	+	0	−	?
Nickel . . .	−	+	+	+				−	−
Chromium . .	+	0	+	+				+	

\+ denotes that the property is increased by the impurity.
− „ „ „ diminished „
0 „ „ „ not affected „
? „ „ various authorities are conflicting.

read before various societies; but with many of them he did not agree, particularly in those cases where the authorities were conflicting. In this compact form however he hoped the table might prove useful, and might be completed and corrected. Amongst the doubtful cases was silicon, of which it had not been definitely ascertained whether it diminished the pliability of mild steel at a white heat, or in other words whether it produced red shortness. Similarly the evidence was conflicting as to whether copper affected the welding qualities of steel; and also as to whether manganese affected its susceptibility to corrosion. The table might also with advantage be extended to include not only other elements but also

other properties, such as melting point, viscosity, limit of elasticity, toughness, &c. Moreover it appeared to him that no one impurity could be said to produce a certain effect when other impurities were present. It seemed as if some of the ingredients intensified, reduced, or entirely reversed the effects of others. Thus the tenacity and hardening qualities were increased, and the elongation and pliability reduced, by carbon; while a further admixture of manganese reduced or reversed all these effects except the increased tenacity. Tungsten and some other ingredients, not included in the table, appeared to agree with silicon and chromium in increasing the property of hardening which carbon gave to iron, and to reduce some of the other properties.

The experiments which had been described in the report constituted in his opinion a new test, which he hoped would help to throw a great deal of light on the properties of steel; for there were various questions which could not be investigated by the tensile or bending tests or by any of the other tests hitherto employed. Thus steel plates often failed cold after flanging; yet when subsequently cut up and tried by tensile, bending, and other tests, the steel was invariably found to be of the best quality. In the bending test he had recently asked friends to try whether any further information could be gained by nicking specimens before bending them. Several results had been sent him, from which it appeared that thin plates of mild steel when nicked could be broken only after bending them through a large angle, if the samples had been properly annealed after being cut off the plates. But thick plates when nicked broke easily under the bending tests. Samples an inch thick could be bent perfectly double without breaking, if they had not been nicked; but if nicked a sixteenth of an inch deep, they broke off short. Pieces cut from plates only half an inch thick could be bent to a right angle after being nicked. In some of these bending experiments three qualities of steel had been tried, having tensile strengths of 24, 28, and 32 tons per square inch; and twelve samples were tested of each quality. It was found that the results agreed fairly well with one another in each of the three sets; but strangely enough the hardest material bent through a larger angle than the medium

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quality. This would show that the nicking of annealed samples before bending would disclose some property of the material not revealed by either the tensile or the temper bending test. It remained to be seen whether this test could be useful in any way for ascertaining the quality of steel; it appeared to him to be a sensitive test, but the data were not yet sufficient. Another test which might throw light upon the quality of the material was to measure its behaviour while being chipped or machined; for it was well known that mild steel was much tougher than iron, although of almost the same chemical composition; and mild steels of identical composition differed so materially in this respect, that with a little experience workmen could tell by chipping a plate in what district it had been manufactured. The difference in toughness might be due, amongst other causes, to the heat at which the steel had been worked; for it seemed a fact that the tenacity of the metal was greatly affected by this cause.

In regard to the experiments made with the miniature ingot shown in Fig. 8, Plate 116, and illustrated by the curves in Fig. 13, Plate 119, it seemed to him that the thermo-junction wires leading to the centre of the ingot would acquire the mean temperature of that distance, and impart it to the junction, so that the latter would not indicate the actual temperature at the very centre of the ingot, but a somewhat lower temperature. The outer hole was so shallow and so near the edge of the ingot that the temperature of the outside was probably shown correctly enough. In connection with the radiation of heat, he might mention some interesting experiments made by Mr. Thomas Andrews, of Wortley Iron Works, Sheffield,* as to the strength of axles at low temperatures. In one experiment a railway axle had been placed in a freezing mixture, of which the temperature was — 4° Fahr., or 36° below freezing point. In order that the cooling of the axle might take place slowly, it was surrounded by an air space of $\frac{3}{4}$ inch. The temperature in the axle was measured with thermometers dipped into mercury, which was deposited in holes drilled in the axle; and in Fig. 19, Plate 123, he

* Proceedings Institution of Civil Engineers, vol. xciv, 1888, pages 180 and 192.

had plotted a representation of the observations recorded. It took 9½ hours to reduce the temperature of the axle from 32° Fahr. down to zero, the freezing mixture remaining 4° lower. A peculiarity which would be noticed in the curve, Fig. 19, was that certain humps occurred in it as the temperature fell: thus at 24° and at 17½° there was a distinct break in the continuity. It might be that these irregularities were accidental, inasmuch as the experiments were not made for the purpose of ascertaining those points, but simply to produce slow cooling of the axle. Another instance had been mentioned by Professor Wedding, at the German Iron and Steel Institute at Düsseldorf in 1888. While explaining that, if a piece of steel which had been polished ready for the microscope were heated to the temperature of molten lead, the structure was far more clearly developed than before, he had remarked as a curious phenomenon that the rate of increase in temperature of the steel received a decided check at this point: so that it appeared as if there was a break in the curve of heating at the temperature of molten lead. In several curves however of the cooling of steel, which he had examined, he had not found any breaks indicating recalescence. The instrument described in the report was one by which he thought it might be possible to detect whether there really was recalescence at any of the above temperatures or not.

Mr. J. E. Stead, Middlesbrough, considered that a great deal of good would probably result from investigation of the kind described in the report. Dr. Anderson's remarks (page 573) had shown how this process of investigation might at once be utilised. With regard to the classification of carbon and other elements into the two classes given in page 544, he thought M. Osmond had in view only their effect in delaying the change of iron from the hard to the soft condition, and not any other effect. Mr. Hadfield's suggestion of re-classifying them, according to the other effects they produced upon steel, would be found most valuable. No doubt they would have to be arranged into a great number of classes. It would not be sufficient to study the effect of only one or two elements; but after these had been studied most thoroughly, a third element must be introduced, and

(Mr. J. E. Stead.)

then the study be begun entirely over again. The combinations in iron and steel were most extraordinary; and the investigation if properly carried out would be so elaborate that few of those present would be likely to see it finished. Mr. Hadfield's remarkable investigations had shown clearly that manganese produced certain effects in iron up to a certain percentage, but different effects with a larger quantity. Investigations with alloys of iron and other metals than manganese must be made in a similar way, right through the whole class, before it could really be understood what effect any particular element had upon iron. In his own experience in the manufacture of steel he had found most extraordinary differences in steel of identically the same chemical composition. Cases of this kind he considered should be carefully investigated; and he believed that the method of investigation described in the report, by means of the thermo-electric pyrometer now exhibited, might throw some light upon the real differences. At present it was very difficult indeed to find out invariably why one steel should be good and another bad.

Mr. J. Macfarlane Gray thought there was not more theory (page 572) in the report now read than in the paper discussed on the previous evening. The method of experiment described in the report was most interesting to himself, because it opened up a way to get at some definite knowledge regarding the constitution of matter and its molecular aggregations. A hypothesis, according to which every physical phenomenon was the result of enormous pressure in the universal ether, had been promulgated in his own paper on the ether-pressure theory of thermodynamics, in which he had shown that a change of molecular aggregation might be a change of effective volume in respect to the ether (Proceedings 1889, page 386). The steps in the cooling diagrams illustrating the present report denoted, in his view, that the total area of matter surface exposed to the ether permeating the molecular interstices was at the same time diminishing abruptly: a diminution of ether-bounding area being necessarily accompanied by evolution of heat, and *vice versâ*. When the small amount of this implied diminution

of effective volume was regarded, and was compared with the mechanical equivalent of the heat thereby evolved, the conclusion was forced upon his mind that the pressure of the ether must be of the order of billions of tons on the square inch. Staggering as this statement was, it was corroborated in every phenomenon of physical science. He believed it would be on the lines of thought set out in his paper on the ether-pressure theory that the features of the cooling diagrams now exhibited would ultimately be explained. In his further paper on the rationalization of Regnault's experiments on steam (Proceedings 1889, page 399) he had attempted, as a test of the ether-pressure theory, to construct a rational formula for the pressure of steam at all temperatures, without any empirical constants. Up to about 28 atmospheres, the highest pressure reached in Regnault's experiments, there was perfect corroboration of the formula (page 445); but above that point the pressures calculated by his own formula were much in excess of those arrived at by the extension of Regnault's formula, and the amount of the disagreement was shown in page 447. In the Comptes Rendus of 25th May 1891 (page 1170) were published the experiments of MM. L. Cailletet and E. Colardeau, made at the Eiffel tower with the use of an open mercury column for pressures; and up to 200 atmospheres their observations of pressure were much more accurately represented by the formula given in his own paper of 1889 (page 440) than they were by the empirical formula constructed upon the experiments themselves and given in the Comptes Rendus of 24th August 1891 (page 328). This corroboration he hoped might tempt others to study that paper, so that it might be applied by some abler men than himself. In the pneumatic calking tool, which had been exhibited in the discussion yesterday evening upon boiler construction, he was glad to recognise a revival of the portable steam riveter exhibited by himself at the Dublin meeting of the Institution twenty-six years ago (Proceedings 1865, page 129); he had had it in use also as a pneumatic calker worked by compressed air. Now it came back from America much improved; and the improvements were appreciated by no one more highly than by himself as the originator. But if it should take another twenty-six years to bring

(Mr. J. Macfarlane Gray.)
the ether-pressure theory similarly to the front again, he could not help wondering whether he should then have an opportunity of reminding the Members of his paper on the subject; he could only hope so.

Professor Roberts-Austen, in reply, said that M. Osmond's classification of the elements alloyed with iron, which had been adopted in page 544 of the report, had been arranged only in accordance with observed facts in regard to the change of state in iron as indicated by the pyrometer. By careful chronographic record M. Osmond had found that the elements in column I did delay the change, and that those in column II did hasten it: those were observed facts. Copper, so far as physical experiments went, he himself quite agreed was not a hardener (page 575); but then it came at the bottom of column I, its volume being 7·1, or so close to that of iron 7·2 that only a little more would have turned it over into the other class; its position therefore should be viewed with some leniency. While there was no evidence to justify the lowering of carbon from the position which it occupied as the steel-producing element (page 576), he considered that boron was entitled to a share in this property; though certainly carbon stood out with such prominence as to be almost unique.

With reference to the statement in page 544—that the elements in column II would act on iron as annealing did, rendering it soft and malleable, "did not their individual properties, or those of their compounds, mask this natural consequence of their presence" —this proviso he was aware qualified the classification adopted. But it must be remembered that nothing was known of the action of these elements in pure iron in such minute quantities as could be strictly compared with those of carbon. Steel almost ceased to be steel if the quantity of carbon exceeded 1·3 per cent. A very hard steel would be produced by no more than 0·8 per cent. of carbon. The effects of other pure elements in so small a quantity were not yet known: that was a subject for future investigation. Again, no one had yet succeeded in getting much chromium or much tungsten into iron, without the simultaneous

presence of a great deal of carbon. It was indeed most desirable to investigate the properties of all the compounds of iron with other elements; but the immediate object with which the present report had been started was to study molecular action; and this was the main object of M. Osmond's classification, which had been reproduced as a quotation in the report, and for which the Research Committee were responsible only as a quotation.

Both Mr. Hadfield and Mr. Stromeyer seemed anxious that the action of elements on iron should be classified; and although he himself considered that the time had not yet come for making such a classification, he nevertheless offered tentatively as a basis for the purpose the following scheme, which appeared to himself and to M. Osmond to possess certain merits. It was still based on the atomic volume of the added impurity; and it showed that, as the atomic volume of the added element augmented, the influence gradually ceased to be beneficial, and ultimately became absolutely prejudicial to the mechanical properties of steel. It should be remembered that the atomic volume of iron was 7·2, a little larger than that of copper.

Added Element, and its Atomic Volume.		Influence of the added Element.
Carbon	3·6	Necessary for effecting the change of iron into steel.
Boron	4·1	
Nickel	6·7	Useful under certain conditions: Nickel in Schneider armour-plates; Manganese in Hadfield steels; and Copper in Schneider steels for special uses.
Manganese	6·9	
Copper	7·1	
Chromium	7·7	Useful in certain conditions, but rather by exerting a reflex action on the carbon, than by direct action of their own.
Tungsten	9·6	
Aluminium	10·6	Useful as reducers, but without much direct action.
Silicon	11·2	
Arsenic	13·2	Prejudicial in all cases.
Phosphorus	13·5	
Sulphur	13·7	

It had been questioned by Mr. Arnold (page 583) whether the plan thus far pursued in this research did not entail a great waste

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of precious labour; and he had deprecated drawing analogies between the action of impurities on gold and on iron. With reference to such a view of the subject, Professor Roberts-Austen observed that those whose position as teachers gave hope that experimental work in the field of metallurgy might in the future be expected from them were too few already; and he wished therefore to say nothing that would discourage anyone at the outset of his career; but he would point out that the tone of Mr. Arnold's remarks would doubtless have been different, had he better understood the nature and object of the Committee's research, which was, as stated at the outset of the report, "to investigate the effects of small admixtures of certain elements on the mechanical and physical properties of iron, copper, and lead." The desire of the Committee, as pointed out in the next sentence, was to extend an investigation previously made upon the application of the "periodic law" to the mechanical properties of metals.

It was widely recognized that phosphorus, sulphur, carbon, boron, silicon, and other elements might be obtained chemically pure, and yet under variations of thermal treatment could be made to pass from their normal state to an allotropic one, in which their properties were entirely altered. This had already been illustrated during the present discussion by the well-known example of sulphur in its elastic form like india-rubber, and in its crystalline yellow condition, the sulphur being equally pure in both states. It might fairly be concluded that physicists in this country and in France had demonstrated that iron could exist in at least two distinct states. Professor H. Le Chatelier, while not attaching so much importance as he himself did to the effect of β or hard iron on the hardening of steel, nevertheless stated that in manganese-iron alloys the iron must be present in the β or hard form. Such men as Pionchon, Ditte, and Le Chatelier were satisfied as to the existence of allotropic iron, which was the basis of much of Osmond's recent work. Now if any metal under investigation could exist in two states, each with widely different properties from the other, it was absolutely necessary at the outset of any research to ascertain which modification of the metal was the subject of examination.

Such an enquiry was nevertheless dismissed by Mr. Arnold (page 583) as wasteful of precious labour, and as offering small prospect of any good result, at any rate in connection with iron and steel. It appeared to Professor Roberts-Austen however, and the Committee entirely shared his view, that it was his first duty to collect experimental evidence for or against the existence of iron, copper, and lead, in allotropic conditions.

In the experiments which were relied upon as indicating the passage of iron from the β or hard to the α or soft state, it was urged by Mr. Arnold (page 585) that the thermal evidence of change afforded by the slight halt in the fall of temperature at the point d in Fig. 12, Plate 118, was too small to mark a gigantic internal convulsion. But, although arguments from analogy had been disparaged by him, it might interest him to learn that the profound molecular change which must occur during the passage of plastic sulphur to its crystalline state was attended by but little thermal disturbance. Time alone would show whether analogies were worth much or little in an investigation of this kind (page 583).

The autographic records of the cooling of pieces of steel, accompanying this report, represented precisely the same facts as the plotted chronograph diagrams illustrating Osmond's paper to the Iron and Steel Institute (Journal 1890, No. I, page 38); and all the data for obtaining curves similar to M. Osmond's were afforded in these autographic curves (page 584). In Fig. 12, Plate 118, the marked prominence at 650° C. in the curve of moderately hard steel was due to the change in the relation of the carbon and the iron which took place as the mass cooled. The corresponding prominence at f in the curve of very soft steel was less marked, because the latter contained so little carbon; but in some cases the heat evolved during the occurrence of the carbon change was sufficient to raise the temperature of the whole mass 100° C. The amplitude of the smaller change at d, which occurred at the higher temperature of 843° C., was doubtless greatly influenced by the simultaneous presence of impurity. This was a subject for future investigation; the point at present to be insisted upon was that this evolution of heat, which occurred when

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the mass cooled down to about 850° C., was seen in its most perfect development in *iron* in which chemists could barely detect the presence of carbon.

The facts mentioned by Mr. Arnold, in connection with the change in structure arising from alterations in the relation between the carbon and the iron, were well known, and had been generally accepted.

It had been pointed out by M. Osmond that, as the proportion of carbon increased in steel, two of the points of recalescence tended to become coincident; and steel containing 0·8 per cent. of carbon should have the maximum effect produced by the two changes when they coincided at about 750° C. or 1,380° Fahr. The carbon point of recalescence *f*, Fig. 12, Plate 118, denoting the change in the relation between the carbon and the iron, tended to shift upwards; while the higher point of recalescence *d*, which was believed to mark the change of what he thought was hard iron into soft iron, tended to shift downwards, approaching the carbon point *f*, until they united and augmented each other.

Only two or three pages of the present report had been devoted to the consideration of steel, in regard to which he had recorded the recent experiments he had himself made in the light of M. Osmond's previous investigations. But in a lecture which he had delivered before the British Association at Newcastle-on-Tyne in 1889, on the hardening and tempering of steel, he had exhibited a number of large coloured diagrams in illustration of Dr. Sorby's admirable microscopic investigations (page 586). These had not been referred to in the report, simply because they did not seem to him germane to the present stage of the investigation: in which he was not dealing with the effect of particular quantities of carbon on iron, such as formed steel, but with the effect of the molecular structure of iron itself; and even this only incidentally. It was partly that lecture however, he believed, which had led Dr. Anderson to recommend that the Alloys Research Committee should be appointed; and he would ask the members of the Institution to bear in mind that this was one of the first efforts ever made to bring the study of molecular physics into contact with the great

mechanical problems of the day. The Committee were investigating the molecular grouping of metals, which underlay their structure; and they therefore employed the pyrometer and not the microscope.

The remarks of Mr. Howe, to whom all English metallurgists who visited America were indebted for so many kindnesses, were enhanced in interest by the admirable volume on steel which he had given to the metallurgical world. There were indeed many anomalies yet to be explained. It was not known as yet what was the extent of the molecular transformations that phosphorus underwent in passing into solution, nor what was the effect of phosphide of iron. When all these questions were cleared up, the answers might be of service in explaining some of the existing anomalies. The investigations as to the existence of "osmotic pressure" in impure liquid metals were now being conducted by Messrs. Heycock and Neville and by himself. It could be shown that the atomic volume of the added impurity did affect the amount by which the freezing point of a metal was lowered (page 581).

As to the belief expressed by Mr. Macfarlane Gray (page 592), that the atomic volume of an element was altered when it was united by fusion with a mass of another metal, the modern investigation of "osmotic pressure," exerted by elements when dissolved in metals, seemed to show that the action of the added element was definite, and that the volume of the element in solution bore a simple relation to its initial volume.

The President said the report now read by Professor Roberts-Austen was only the commencement of this research, and no pretence was made of having reached finality on any point. But however unlikely it might be that either Mr. Macfarlane Gray (page 594) or himself would see the end of it, he certainly looked forwards to seeing at any rate some further instalments of it. Meanwhile he had great pleasure in asking the members to join him in giving their best thanks to Professor Roberts-Austen for this first instalment of his labours in the important research which had been started at the welcome suggestion of Dr. Anderson.

Mr. Walter Bagshaw wrote to call attention to a phase in the behaviour of melted metal, which at present had been but little examined: namely the configuration on the surface of molten metal, particularly cast-iron, popularly known as "flowering," from the size and pattern of which some indication of the physical properties of the metal when cold might be gleaned. Some time ago he had endeavoured to photograph melted metal in his foundry; but, owing he believed to imperfect appliances, he had not succeeded in obtaining an outline visible to the naked eye. If a series of photographs of these casting flowers could be taken, and tabulated with the chemical analysis of the metal, the breaking weight and deflection of a test bar, and the photograph of its fracture, it seemed likely that useful information might be gained; for he was confident that there was more in the rough and ready inspection of the metal in the ladle than was admitted by those not practically engaged in the foundry.

Another point of interest, of which a satisfactory explanation would prove a boon to ironfounders, was the common practice in the foundry, when a casting free from blow-holes or other imperfections was required, to feed the mould with frequent supplies of fresh metal, which was pumped in by a rod worked up and down in the runner. During this operation the outside of the runner solidified and formed a tube, through which additional metal was forced into the casting; there was thus a liquid centre, surrounded by a solid exterior, with an intermediate pasty material, the three states blending in imperceptible gradations. The question arose whether a casting artificially fed in this manner was as free from internal strains as one left to undergo natural shrinkage. Practice would seem here to be opposed to theory.

Mr. Edward B. Marten, Member of Council, wrote that it had occurred to him that sulphur—which in its crystalline or common condition and its elastic state had been referred to by Professor Roberts-Austen as illustrating allotropic forms of matter—was the agent which turned india-rubber from its elastic or common state into the exceedingly hard vulcanite now so much used in electric

work. Was there any analogy between this effect and the effect of alloys on metals? and would microscopic investigation of these substances be likely to reveal any similarity of molecular structure to that of iron, or of iron with alloy of carbon in the form of steel? India-rubber being an organic compound might indeed be thereby excluded from comparison with metals; but even if the present investigation could not be at all assisted by the analogy of materials dealt with at such low temperatures, their analogy might at least help to make an abstruse subject somewhat clearer to the uninitiated, in the same forcible way in which, on a former occasion (Proceedings 1883, page 79), Professor Hughes had made clear his ideas of the effect and condition of molecules of iron and steel under electric influence, by study of iron filings loose and fixed with wax.

Mr. George Addy wrote that attention had been drawn by Professor Roberts-Austen in page 564 of his report to the interesting information afforded by the pyrometer in connection with the measurement of internal stresses in iron and steel; and it was added that the occurrence of the molecular changes in steel must be of vital importance when the metal was subjected at high temperatures to mechanical operations such as rolling or forging. This was a subject on which reliable information would be highly acceptable; and the experiments which had been made with the miniature ingot of mild steel, four inches diameter and eight inches long, were certainly a step in the right direction. It appeared to him desirable however to point out that, although the upper curve in Fig. 13, Plate 119, was said to record the cooling of the centre of the ingot, what it actually did record was simply the cooling of the bottom of an open hole drilled down in the centre of the ingot. This hardly represented the centre of an ingot in the usual acceptation of the expression; and the cooling thus recorded must in his opinion be altogether different from the actual cooling of the centre of an ingot, either in a state of quiescence or during the process of rolling or forging. Although between the points A and B in Fig. 13 the portions of the two curves that had been obtained from the two holes drilled in the miniature ingot as shown in Fig. 8, Plate 116, might afford some general idea of the great

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internal strain which must be set up during the cooling of a piece of steel of the size experimented upon, such an indication he considered must not be taken as applying to a real ingot just turned out of the mould. If it were possible to record, simultaneously with the heat of the exterior, the heat also in the interior of an ingot during cooling —not of a hole drilled in the centre of an ingot—a different condition he believed would be revealed from that represented by the portion of the curves between A and B in Fig. 13.

When making a series of experiments about two years ago with armour-piercing projectiles, for which a pyrometer that could be relied on for high temperatures would have been most useful, he had found as the result of enquiry that no trustworthy pyrometer could be obtained except for comparatively low temperatures. It had consequently been necessary to make other arrangements, which, although satisfactory in the long run, had entailed considerable trouble and anxiety at the time. He was glad therefore to hear of the accuracy of the Le Chatelier pyrometer now described, when used for high temperatures.

This report opened a wide field for investigation; and he trusted that Professor Roberts-Austen and other members of the Research Committee would shortly communicate further information on steel, as this appeared to be the material which most closely interested mechanical engineers.

Professor Alexander B. W. Kennedy, Vice-President, wrote that of the many points of interest opened up by the work done by Professor Roberts-Austen for the Alloys Research Committee he should like to emphasize one only. The investigation really seemed to him to bring engineers somewhat nearer to the causes of one of their great troubles, namely the existence of latent stresses in materials supposed to be unstrained. If Dr. Anderson's suggestion (page 573) could be carried out, it might be possible to find out, by the behaviour of turnings or other small portions of a material, whether its physical nature had been altered: whether for instance, if a bar of iron were bent cold, any change took place at the bend to cause it to differ from the unbent part of the bar. Or, perhaps even in cast-iron,

whether the different rates of cooling in different portions of a casting left such traces in the constitution of the metal as could afterwards be detected by the extraordinarily delicate apparatus now exhibited. He did not understand Professor Roberts-Austen to say that he could already go so far as this; but he hoped that further work in this direction might enable some results of the kind to be obtained. Would turnings from the fractured surface of a test bar, for instance, which was always somewhat strongly magnetic, give results with the thermal method different from those given by turnings from other portions, strained or unstrained, of the same bar? Though he had not himself used the thermo-electric pyrometer, he hoped to do so: among other purposes, for measuring the temperature of flue gases.

From the promising start already made, the work of the Alloys Research Committee he thought would prove at least as important as that of any of the other Research Committees of the Institution; and he looked forwards with much interest to further communications from Professor Roberts-Austen.

Professor Roberts-Austen wrote that the interesting remarks of Mr. Marten (page 600) seemed to be much to the point, for it was more than probable that the effect of sulphur on india-rubber presented analogies to the influence of carbon on iron; but the problem was one of such terrible complexity as to deter workers from attacking it at present. Moreover it must be remembered that the percentage of sulphur in india-rubber was large. As an organic compound, india-rubber was by no means excluded from comparison with compounds of carbon and iron, which were almost organic in their nature; and the general tendency of modern research was to break down the distinction which had hitherto existed between alloys and organic compounds.

In regard to Mr. Addy's recognition (page 601), which was much appreciated by himself, of the value of the experiment represented in Fig. 13, Plate 119, it was of course true that the upper curve represented the cooling at the bottom of a hole drilled down in the centre of the ingot, and that this hole was not absolutely closed. It could not be said however to be an "open" hole, for it was filled as

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nearly as might be by the pyrometer wires and their insulating tubes; and it was for the sake of clearness that the size of the orifice was exaggerated in the drawing. Filling such a hole with a fusible metal, as was usual in conducting physical experiments at comparatively low temperatures, so as to ensure complete thermal con'act, would not have met the case.

MEMOIRS.

Auguste Bernard Albaret was born at Dax in the department of Landes, France, on 20th July 1824. After having received only the most elementary instruction in his native town, he nevertheless succeeded in his sixteenth year in passing the examinations necessary for obtaining admission into the Ecole des Arts et Métiers at Angers. On the completion of his studies there in 1843, he served as assistant engineer on board the steamers "La Chimène" and "Le Cerbère." From 1844 to 1848 he was successively a working fitter, erector, and draughtsman in several important works in Rouen and Paris. In 1848 he became an engine-driver on the railway from Paris to Lyons; and in the following year was made works manager of the repairing shops in Paris belonging to that railway. In 1857 he was appointed inspector of the work that was being done at various establishments in France and England for the Paris Lyons and Mediterranean Railway. After spending some time as engineer in the locomotive works of MM. Cavé, he was occupied in 1858 in establishing the works of the Madrid Saragossa and Alicante Railway for the construction of their rolling stock. In 1859 he became locomotive engineer of the Portuguese Railways. On the death in 1861 of M. Duvoir, manager of the agricultural engine works at Rantigny, near Liancourt-sous-Clermont, in the department of Oise, he was appointed his successor; and he greatly enlarged the works, until they now employ more than 400 men. During the thirty years that he continued at the head of this establishment, the work he turned out became known throughout all parts of Europe and also in America, comprising large numbers of stationary and portable engines, thrashing machines, and many other agricultural implements. By assiduously attending the various agricultural meetings and competitions, he made himself practically acquainted with the requirements of farmers both in France and in other

countries, and gained large numbers of prizes for the machines he exhibited on these occasions as well as at the great international exhibitions. He received the successive distinctions of the Legion of Honour, in recognition of the important services he had rendered to the progress of agriculture. He was a justice of the peace for the canton of Liancourt, and for many years was mayor of Rantigny, where his death took place on 24th January 1891, at the age of sixty-six, while he was still actively occupied in his manifold engagements. He became a Member of this Institution in 1858.

Samuel Barratt was born at Harpurhey Hall near Manchester on 10th August 1843, being the son of a corn-merchant in Manchester. After leaving school he travelled in the United States for nearly three years; and on his return was apprenticed in the works of Messrs. John Penn and Sons, Greenwich. On the completion of his apprenticeship he went to the works of Sir Joseph Whitworth, Manchester, for about a year and a half; and left there to take the post of draughtsman at the Gaythorn gasworks, where he eventually became manager, and there carried out several alterations and improvements in connection with the late city surveyor, Mr. Lynde. After holding that position for thirteen years, he was promoted to the gasworks at Rochdale Road, where he continued until within a few weeks of his death, which was accelerated by the anxiety attendant on the gas stokers' strike. He died on 26th July 1891, in the forty-eighth year of his age. He became a Member of this Institution in 1879.

Thomas Comings Hide was born at Camberwell on 12th October 1825, being the son of Mr. G. E. Hide, comptroller to the General Post Office, London. Though educated with a view to the church, his taste for mechanics proved so strong that in April 1842 he was articled for five years as a pupil to Messrs. Miller and Ravenhill, marine engineers, of London. At the expiration of his articles, he was engaged as a draughtsman by Mr. Heseltine of Bow, whence in 1848 he went as second engineer on board the "Ranger," one of the small screw-steamers at that time employed in the cattle trade.

Subsequently he joined the "Ondine," a vessel belonging to Mr. Baldwin, the proprietor of the "Morning Herald," employed in carrying despatches across the channel on the Dover station. In January 1849 he accepted an appointment as second engineer on board the paddle-wheel frigate "Bombay" of 400 horse-power, then fitting out for the republicans who were actively engaged in Italy at that time of political complications; but as the vessel on completion was not permitted by the British authorities to leave the Thames, he entered the German navy in February 1850 in the same capacity, and joined the "Cacique" then lying at Bremen, and was subsequently appointed chief engineer to the "Barbarossa" in the same fleet. In February 1853 he entered the service of Messrs. Robert Stephenson and Co. of Newcastle-on-Tyne, as outdoor manager in their marine engineering department; and left them on accepting the office of chief engineer of the screw frigate "Carlo Alberto," ordered from that firm by the Sardinian government. Subsequently taking part in the operations in the Black Sea during the Crimean war, he was publicly thanked by the admiral of the fleet for the valuable services he rendered during that period. On his return to England he accepted an appointment under Mr. Miller, who had retired from active business in 1852, and with whom he continued until Mr. Miller left for America, where he subsequently died. In 1858 he became manager to Messrs. John and Alfred Blyth of London, with whom he remained about four years. In 1862 he commenced business on his own account as a consulting marine engineer in Fenchurch Street, where amongst other work he designed light-draft steamers for the Rhine, Danube, Euphrates, and Weser, and was largely engaged in the preparation and outfit of blockade runners during the American civil war which had commenced in 1861. In 1869 he received the appointment of chief engineer to Kidderpore Dockyard, Calcutta; but on account of the ill-health of his wife he had to return to England in the following year, when he took offices in Cullum Street, in partnership with Mr. Thompson until 1878. Having been appointed consulting marine engineer to the Indian State Railways, he carried out a great amount of work, principally light-draft stern and side paddle-

wheel steamers and barges. On the introduction of torpedo boats he was also consulted by friends on various questions connected therewith. At the end of 1890, finding that his physical powers were no longer equal to the discharge of his duties, he retired from business; but he gradually became weaker from creeping paralysis, and passed away on 8th October 1891 in the sixty-sixth year of his age. He became a Member of this Institution in 1864.

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BOILER CONSTRUCTION.

Plate 107.

Lap-Joints.

Thinning of Corners of Plates.

Thinned by machine.

Thinned from fire.

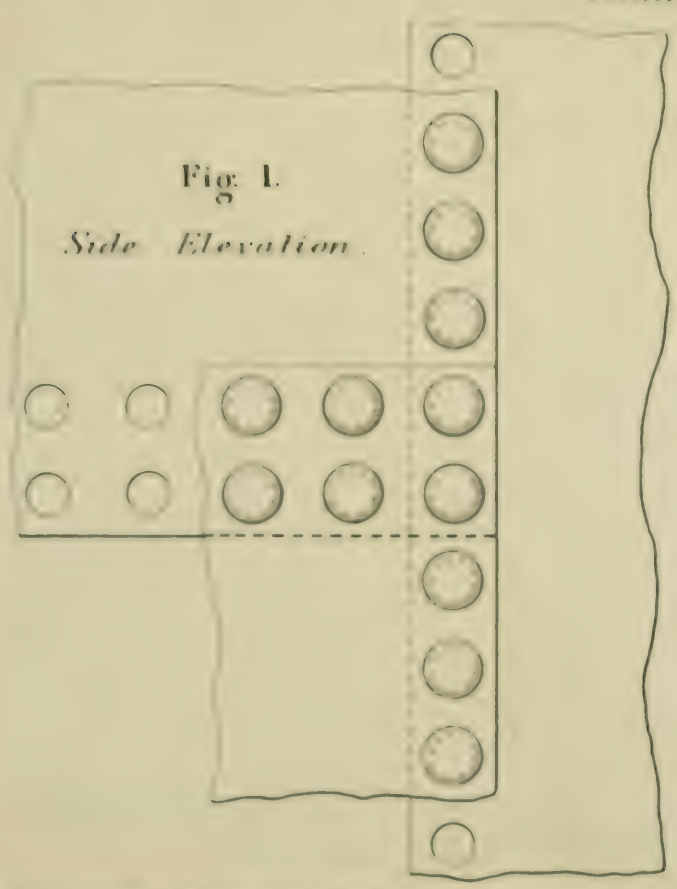


Fig. 1.

Side Elevation.

Fig. 2. *Transverse Section.*

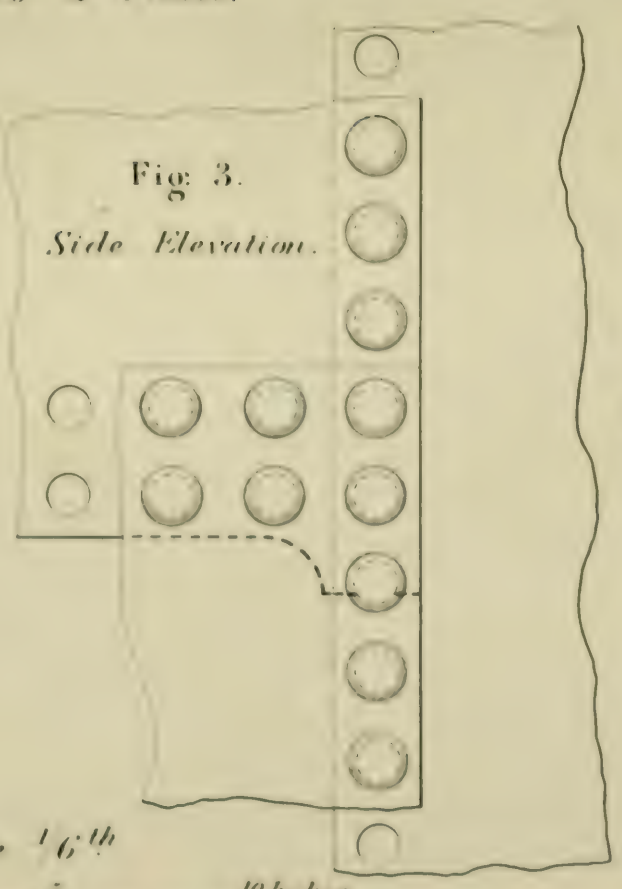


Fig. 3.

Side Elevation.

Fig. 4. *Transverse Section.*

Scale 1/6th

0 5 10 Inches

Mechanical Engineers 1891.

Plate 107.

Strap end butting

Butt Joints.

Strap end thinned and tucked under.

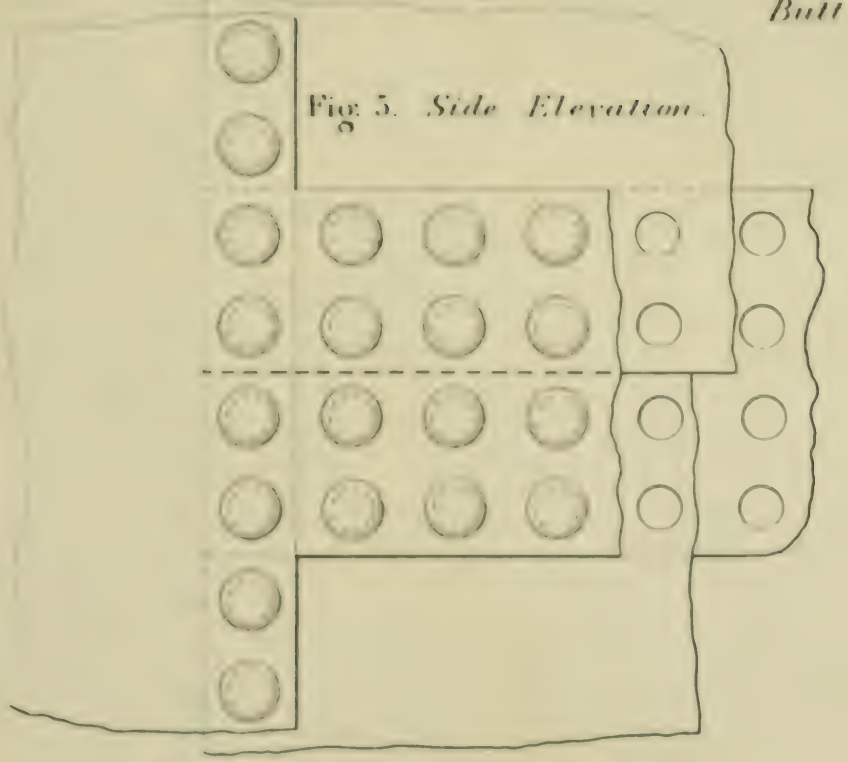


Fig. 5. *Side Elevation.*

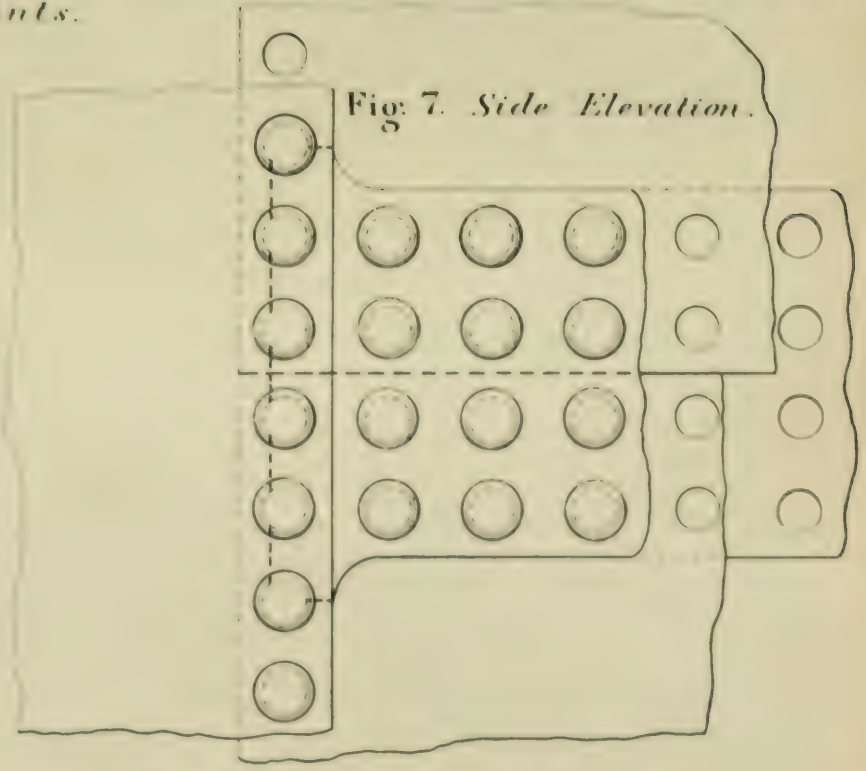


Fig. 7. *Side Elevation.*

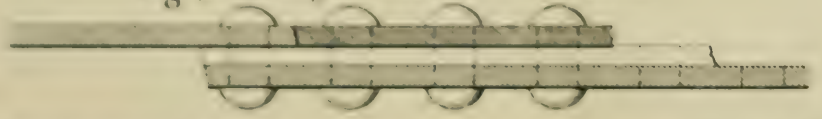


Fig. 6. *Longitudinal Section.*

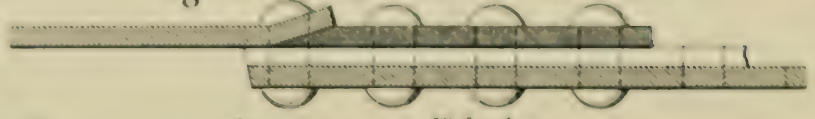


Fig. 8. *Longitudinal Section.*

Mechanical Engineers 1891.

Scale 1/6th

0 5 10 Inches

Plate 108.

BOILER CONSTRUCTION.

Fig 9.
Local Heating of Steel Plate

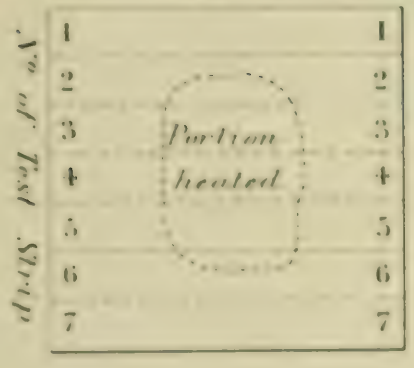
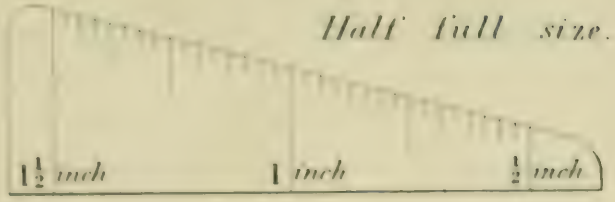


Fig 10. *Taper Gauge for measuring deflection of end plates.*

Half full size.



Edges of Plates.

Fig 11. *Before Fullering.*

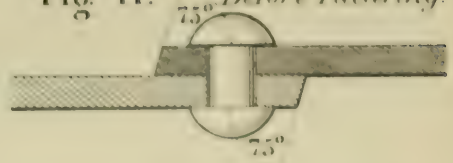
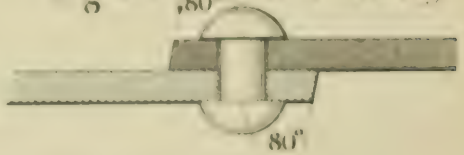


Fig 12. *After Fullering.*



Attachment of Flues to End Plates.

Fig 13.
Angle Ring

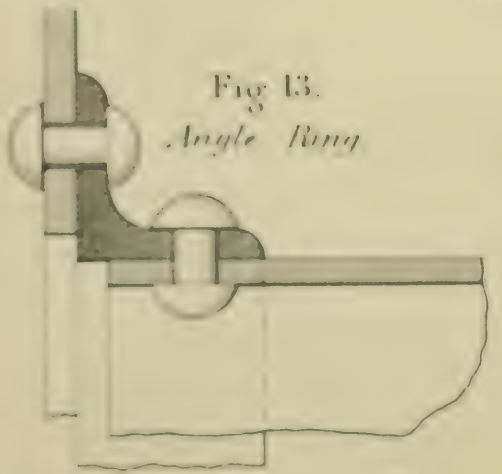


Fig 14.
Flanged Flue

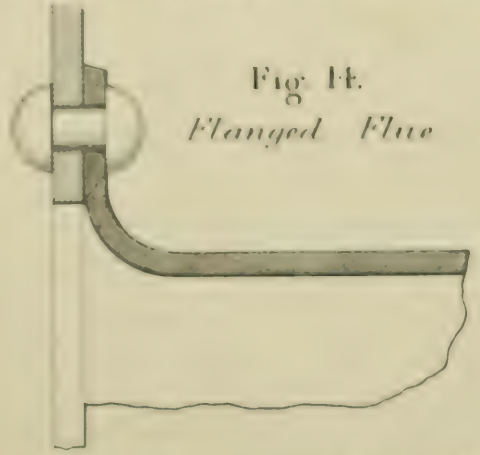
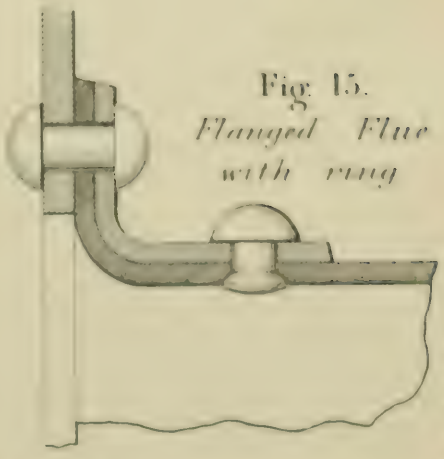


Fig 15.
Flanged Flue with ring



Mechanical Engineers 1891

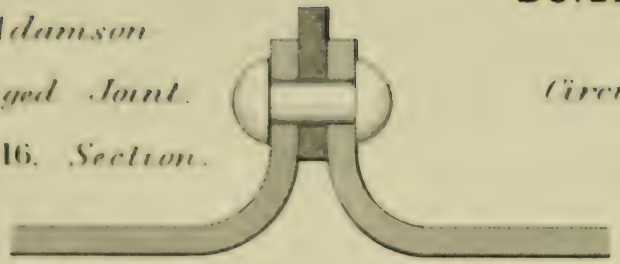
Scale 1.4th

BOILER CONSTRUCTION.

Plate 110.

Adamson Flanged Joint.

Fig. 16. *Section.*



Circular Joints of Flues.

Scale 1/4th

Bowling or Bolton Hoop.

Fig. 18. *Section.*

Fig. 17. *Elevation.*

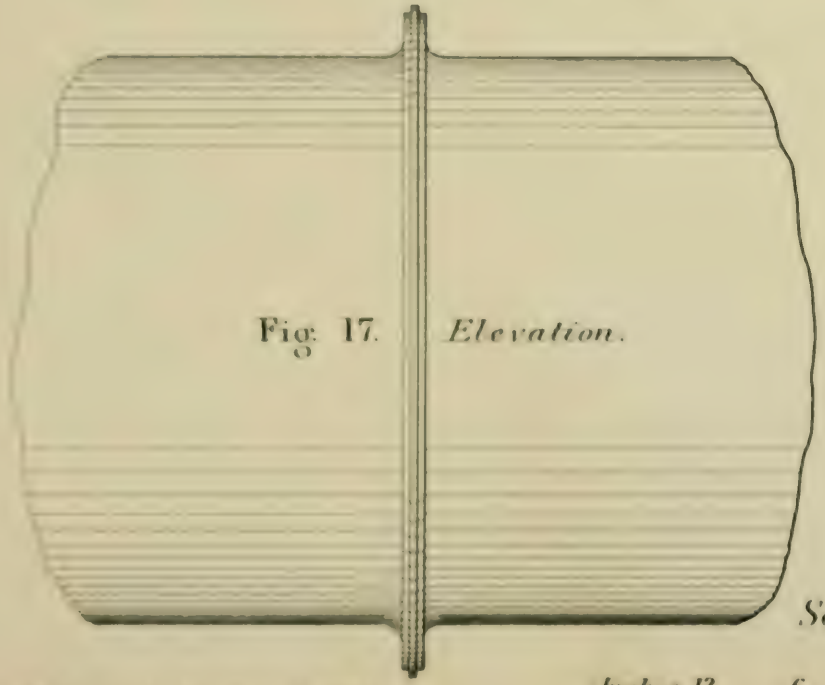
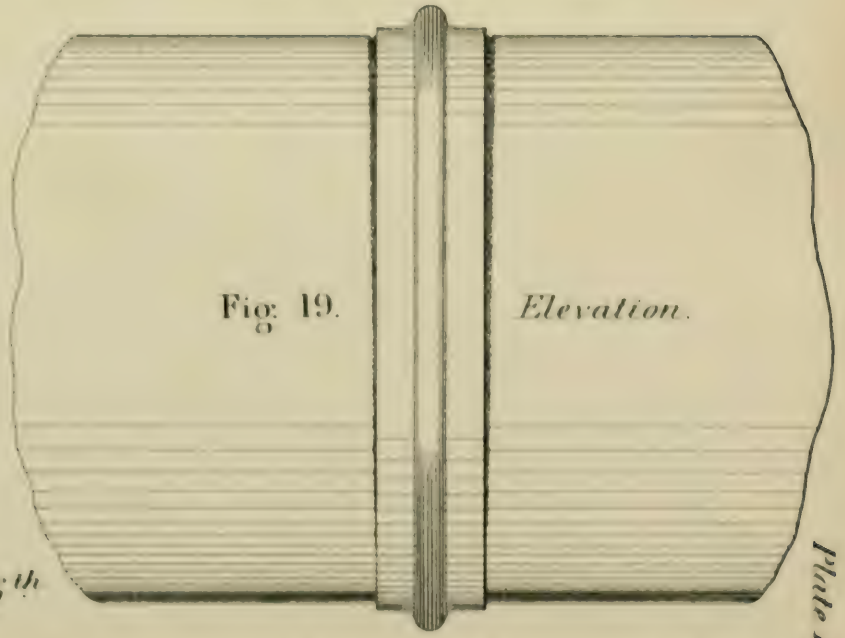


Fig. 19. *Elevation.*

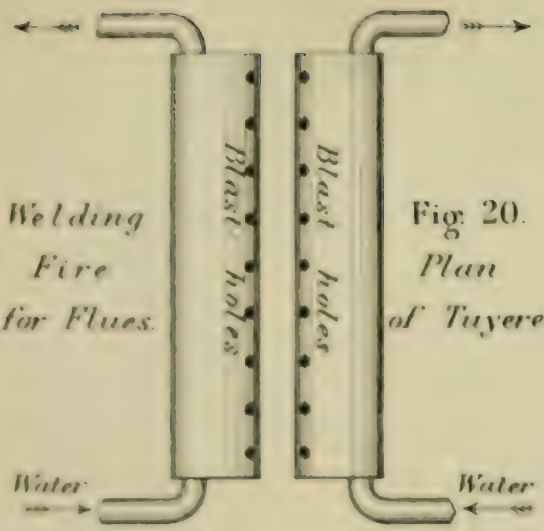


Scale 1/16th

Inches 12 6 0 1 2 3 4 Feet

Mechanical Engineers 1891

Plate 110.



Welding Fire for Flues.

Fig. 20. Plan of Tuyeres.

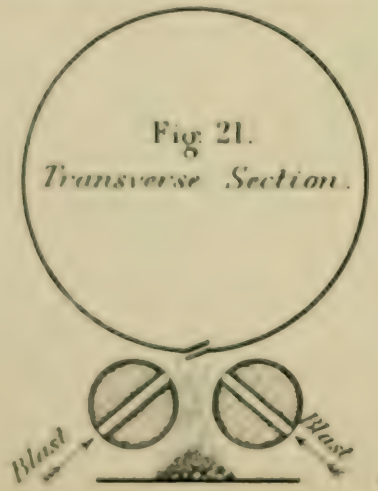
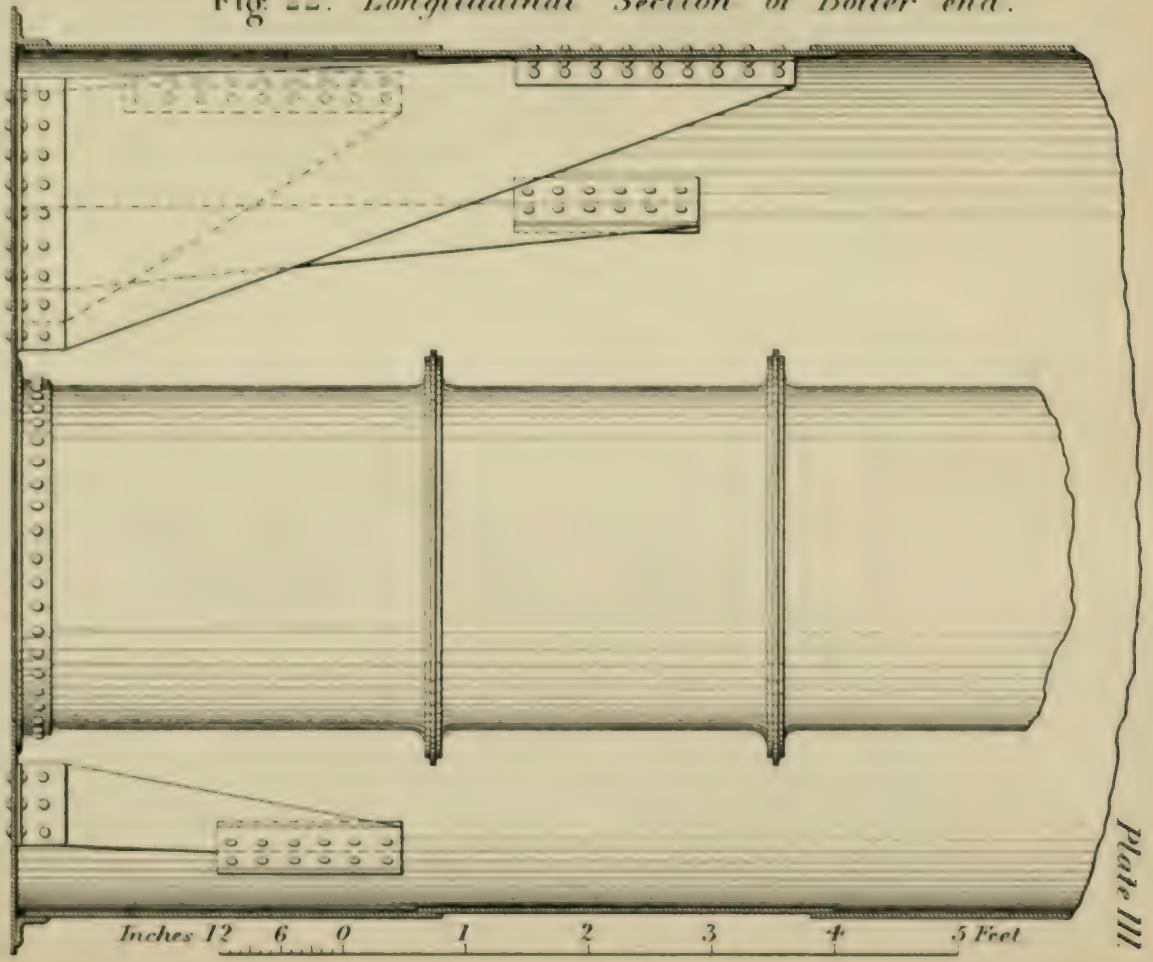


Fig. 21. Transverse Section.

Scale 1/24th

Fig. 22. *Longitudinal Section of Boiler end.*



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Arrangement of Gusset Stays.

Fig. 23.

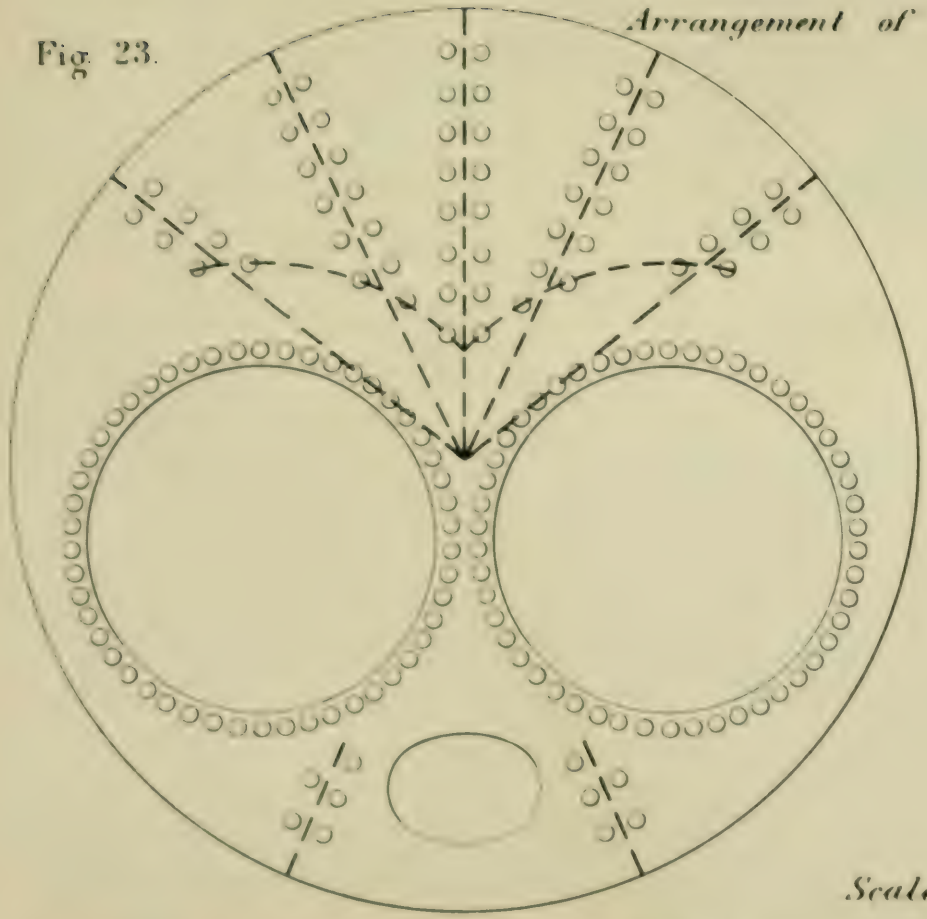
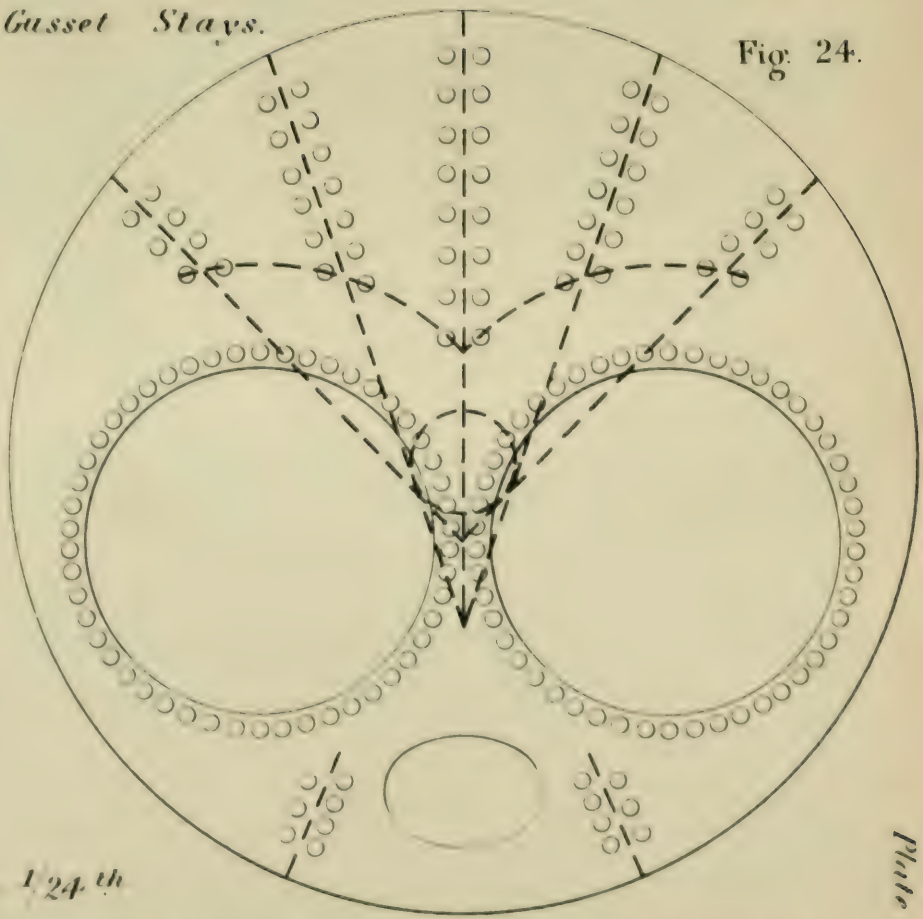


Fig. 24.



Scale 1/24th

Inches 12 6 0 1 2 3 4 5 6 7 8 *Feet*

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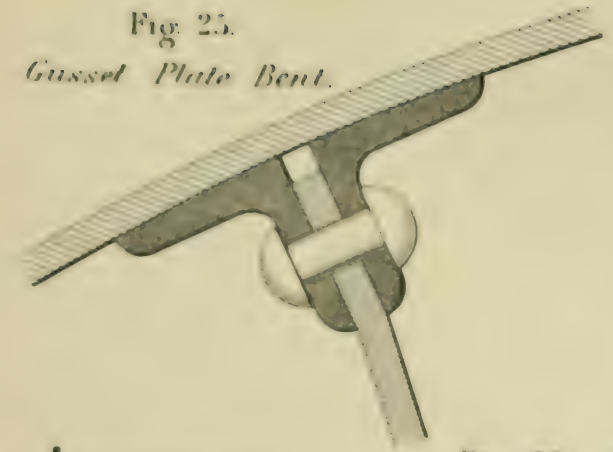
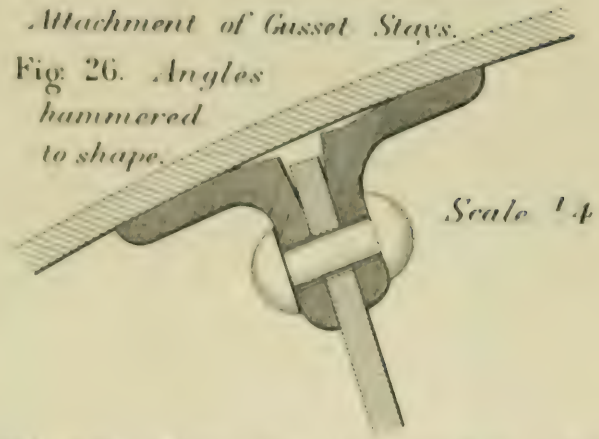
Plate 112.

Fig. 25.
Gusset Plate Bent.



Attachment of Gusset Stays.

Fig. 26. *Angles hammered to shape.*



Scale 1/4th

Fig. 27.
Angles re-rolled.

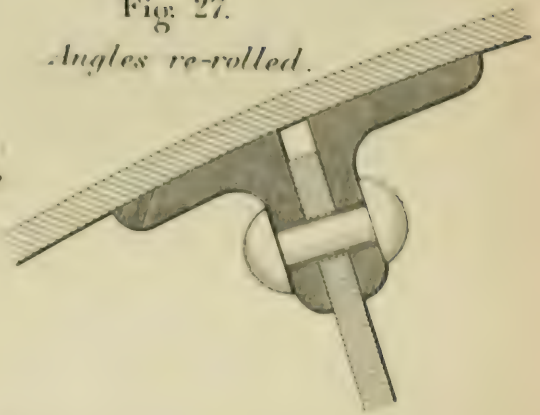
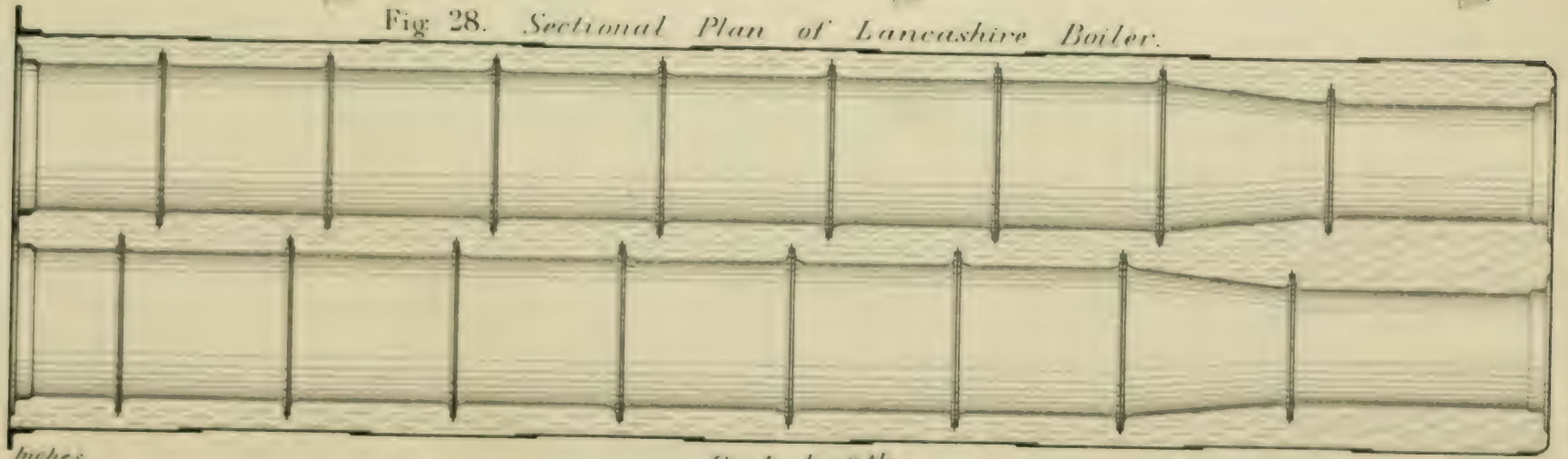
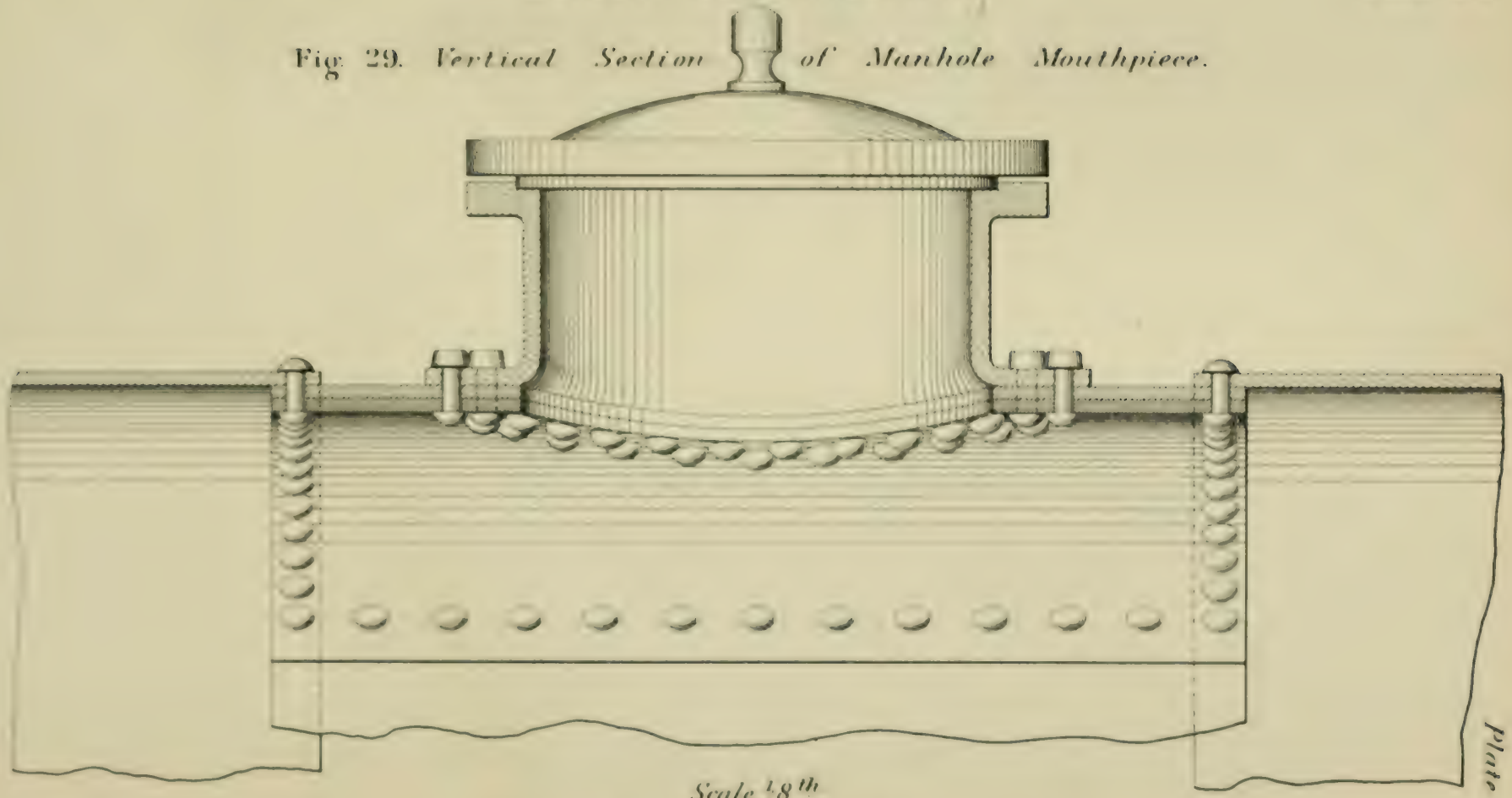


Fig. 28. *Sectional Plan of Lancashire Boiler.*



Scale 1/48th

Fig. 29. *Vertical Section of Manhole Mouthpiece.*



Scale 1/8th

0 5 10 15 20 Inches

Fig. 1. *Thermo-Electric Pyrometer.*

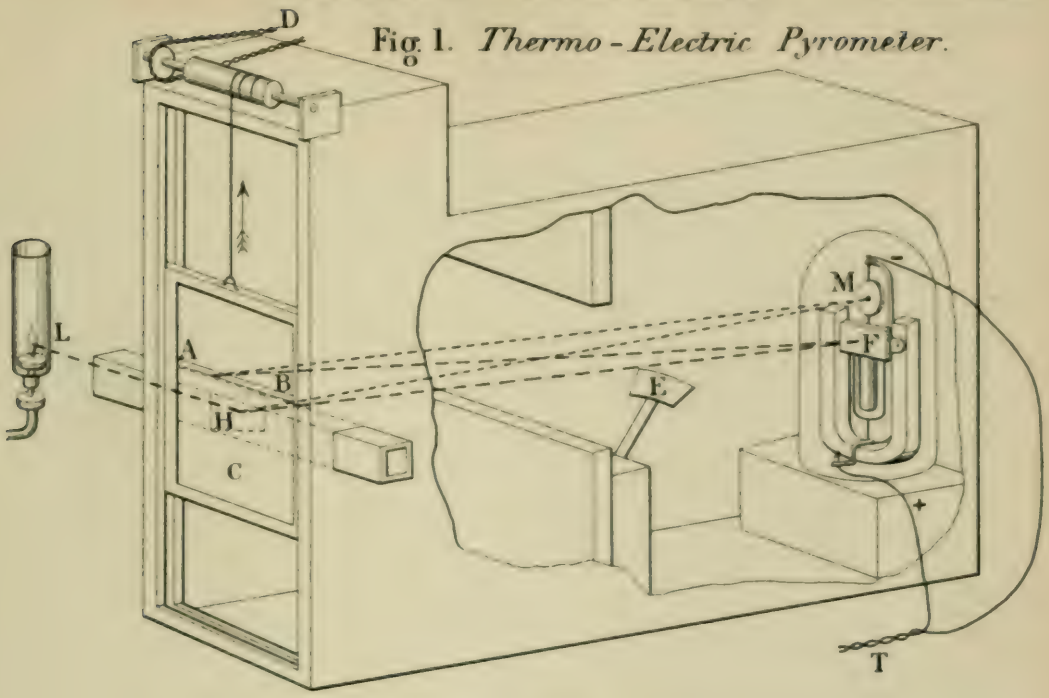
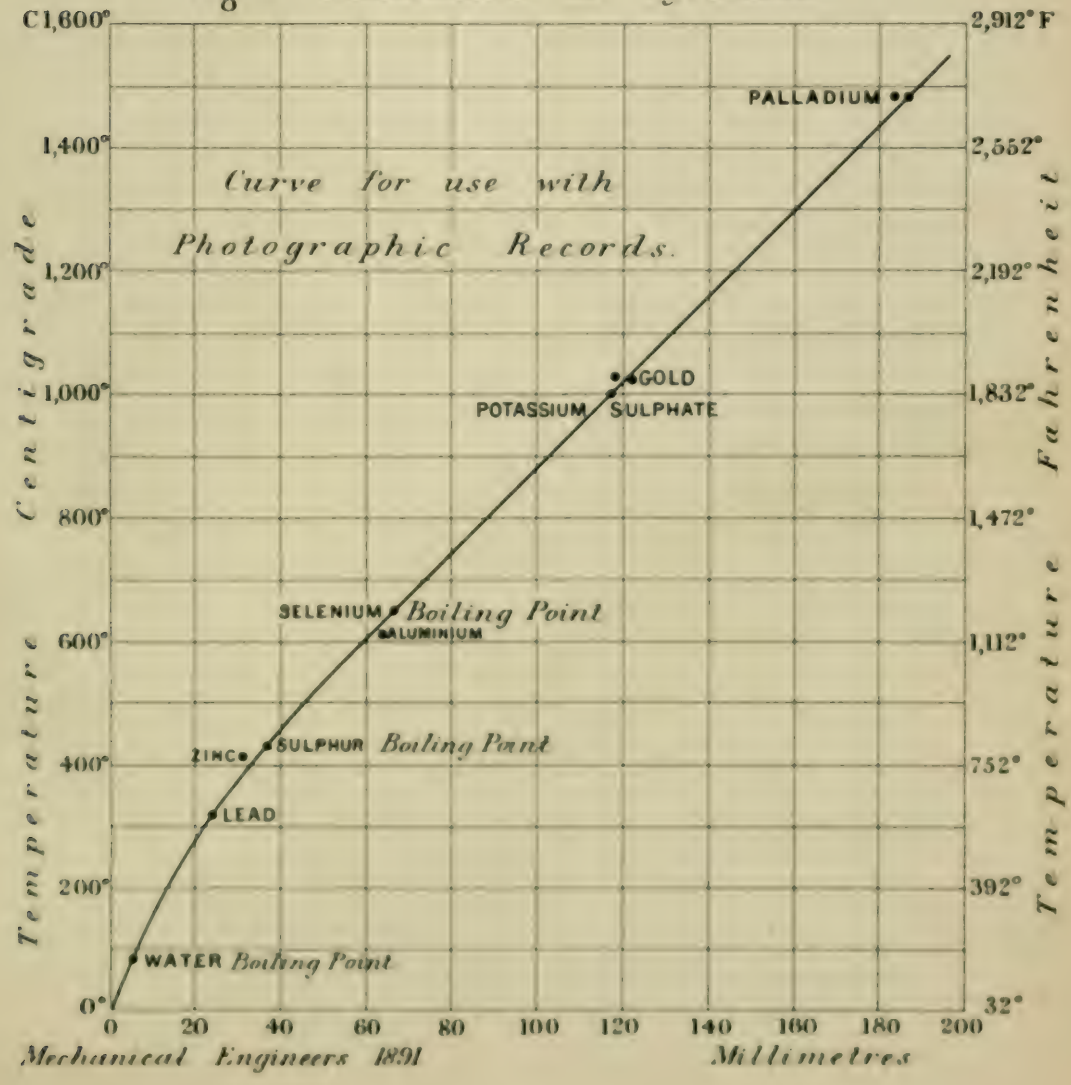


Fig. 2. *Calibration of Pyrometer.*



Thermo-couple.

Fig. 3.

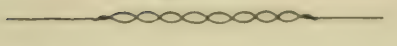


Fig. 4.

Fig. 5.

Galvanometer.

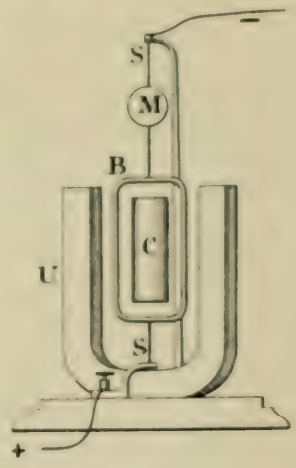


Fig. 6.

Crucible.

Fig. 7.

Silver-Copper Alloy.

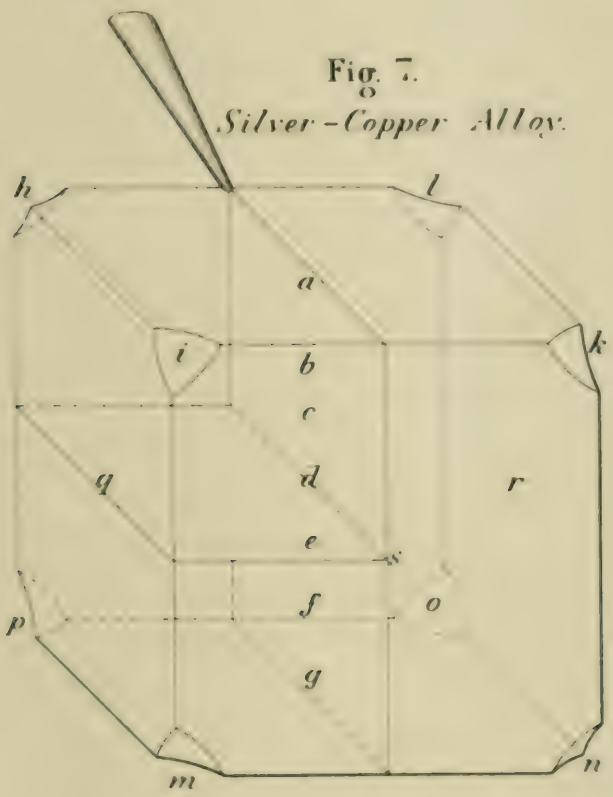


Fig. 8.

Section of Ingot.

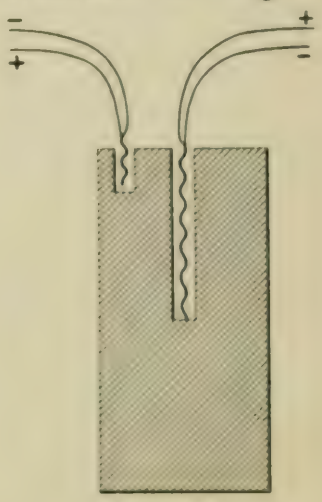
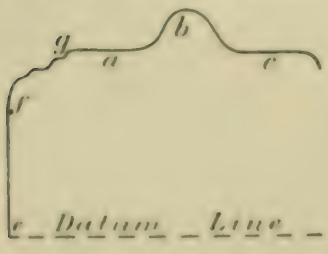


Fig. 9.

Fusion and Solidification of Aluminium.



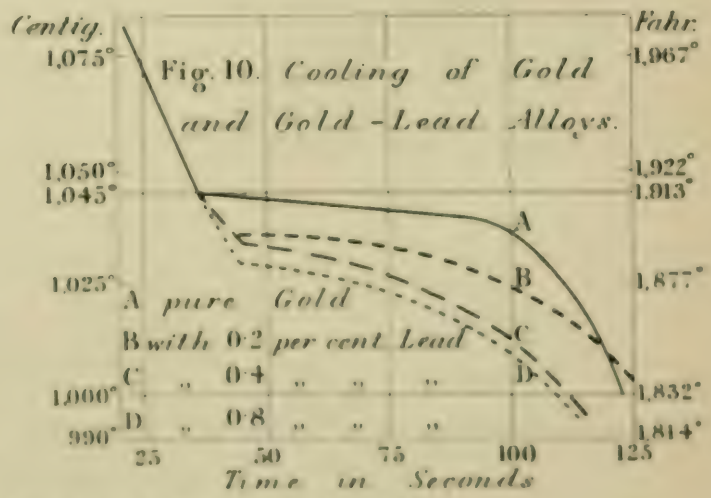


Fig. 10. *Cooling of Gold and Gold-Lead Alloys.*

A *pure Gold*
B *with 0·2 per cent Lead*
C " 0·4 " " "
D " 0·8 " " "

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Fig. 11. *Cooling of Silver.*

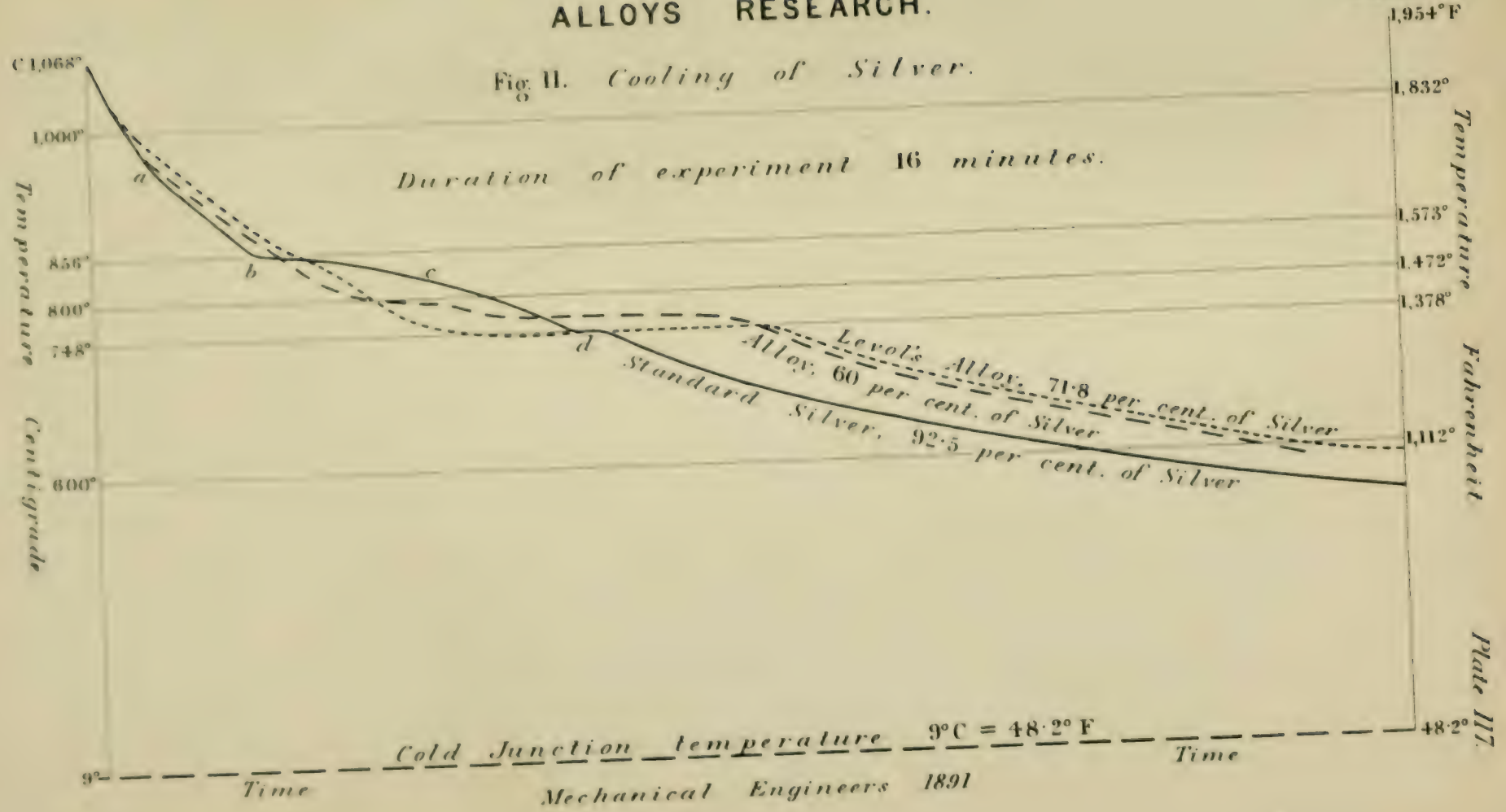

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Fig. 12. *Cooling of Steel.*

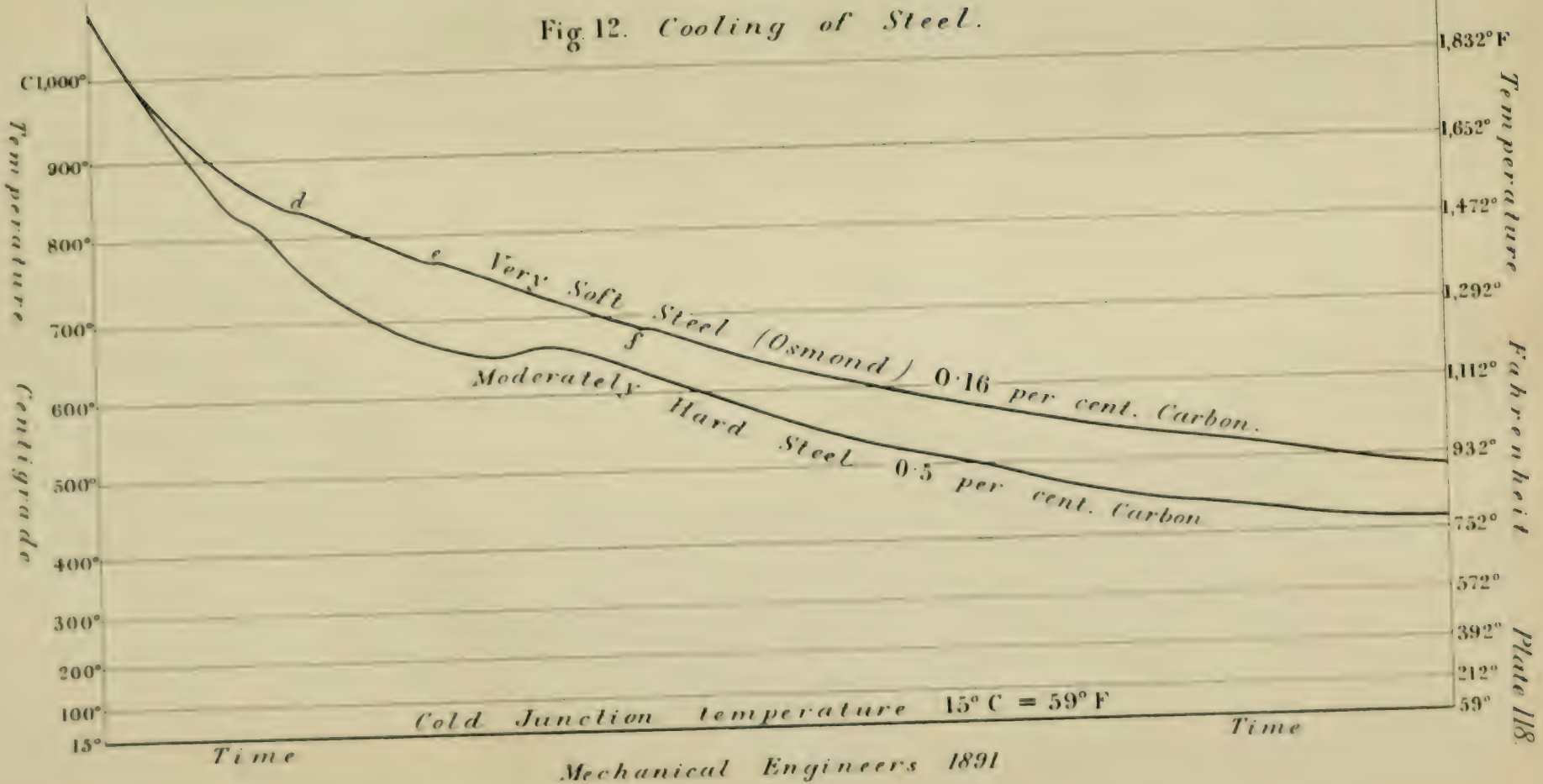

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Plate 118.

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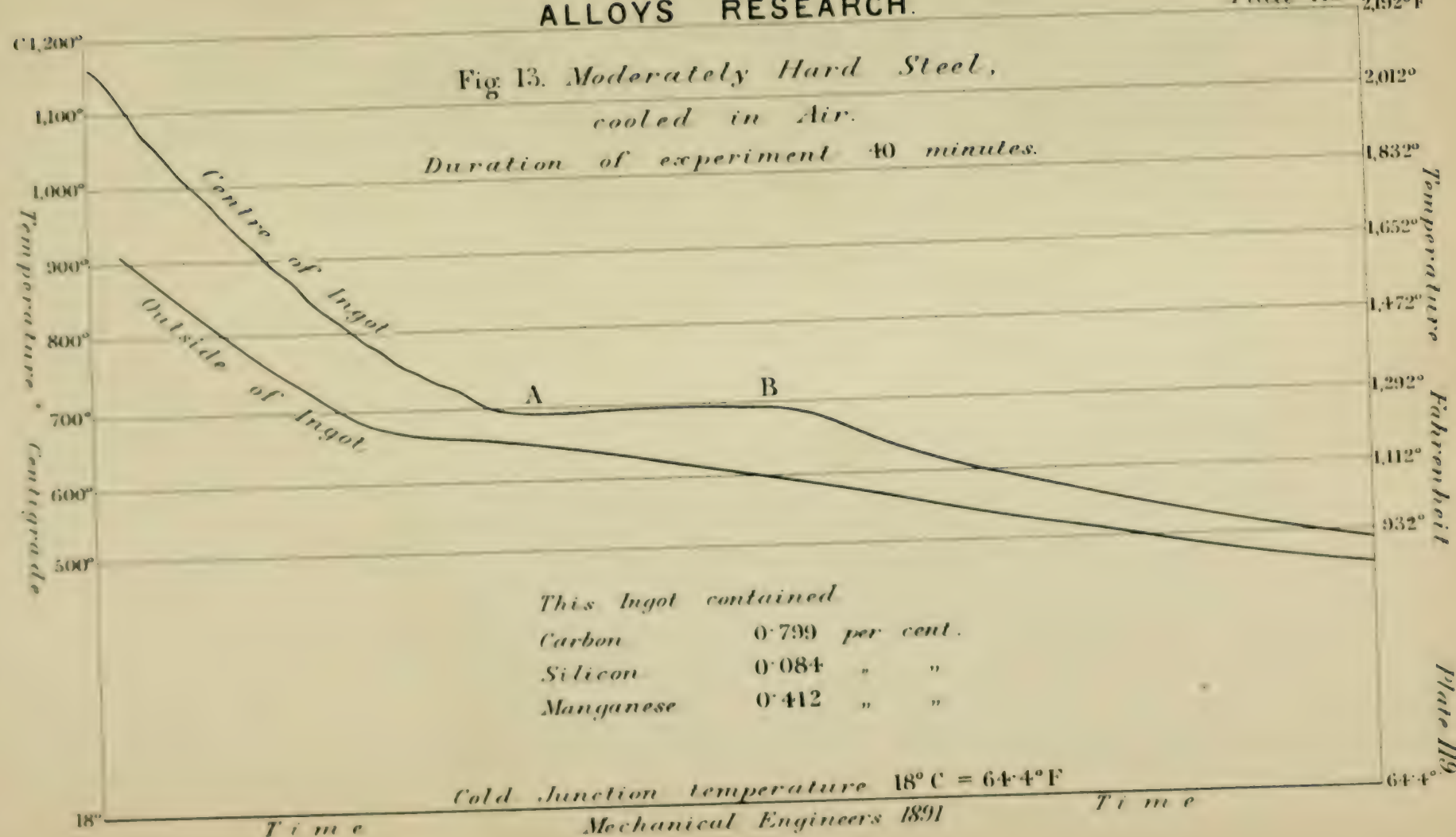

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Plate 119.

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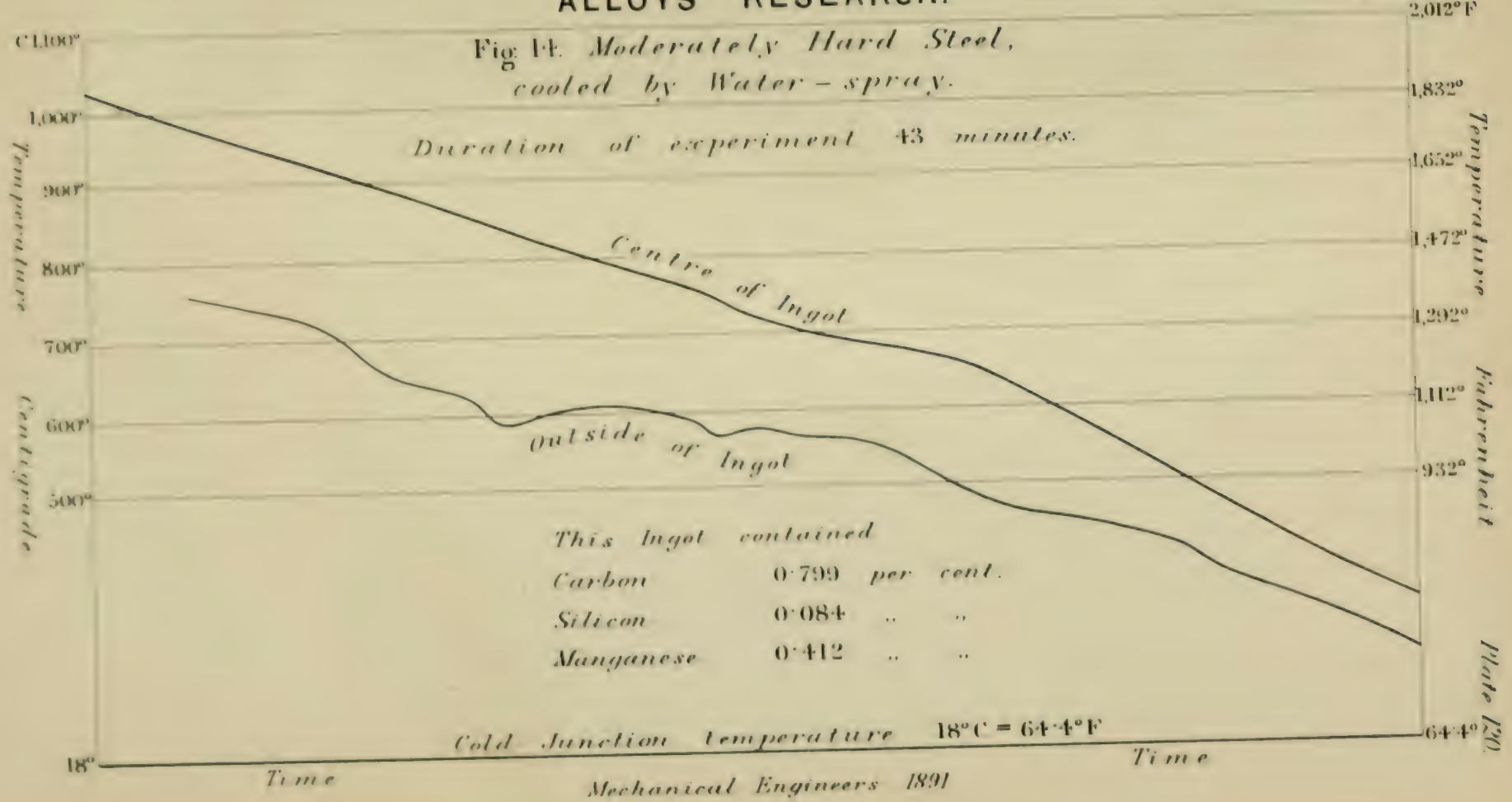

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Plate 120.

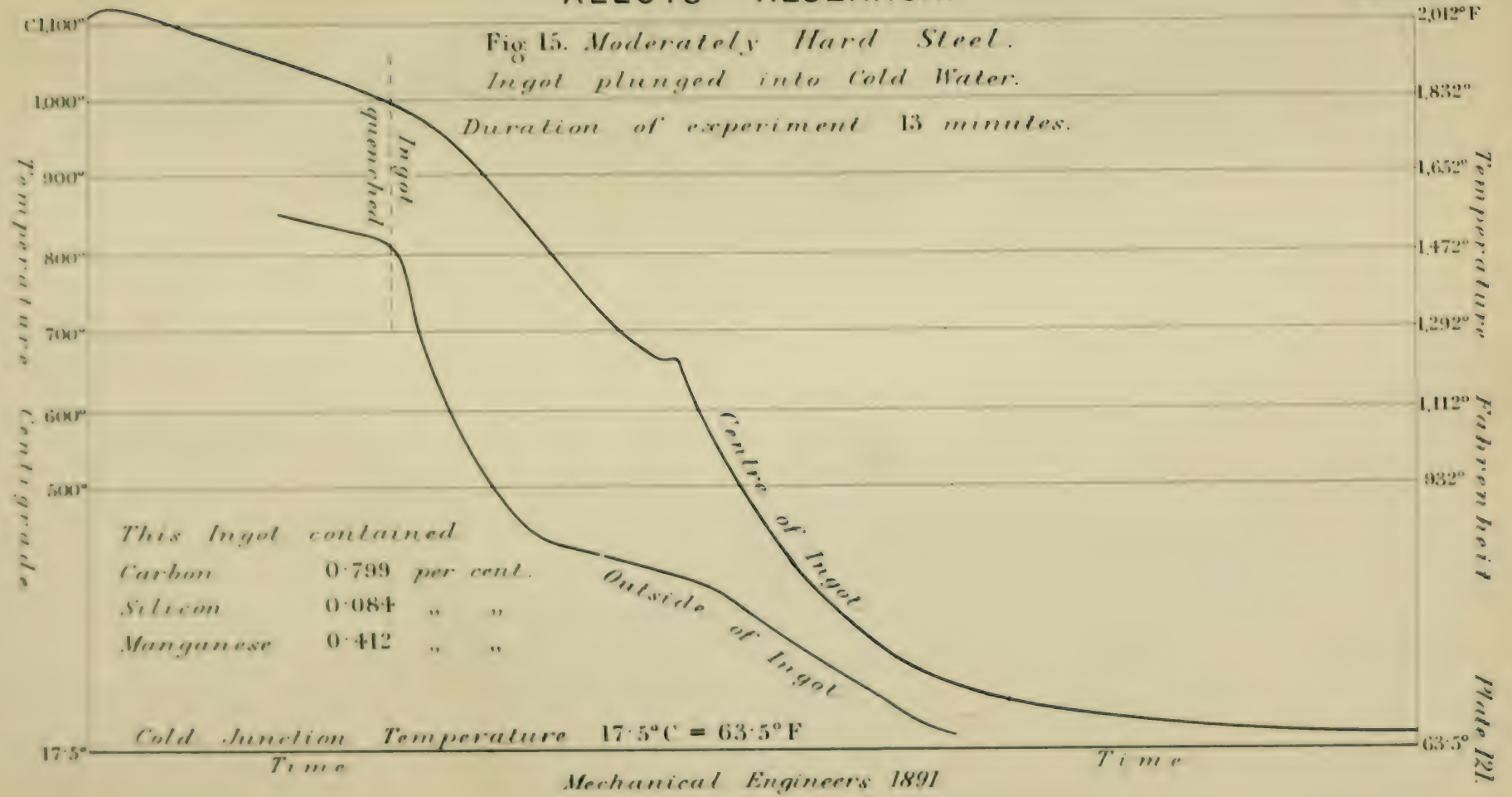

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Plate 121.

Fig 16. *Atomic Volume of Elements and Tensile Strength of Gold alloyed with 0·2 per cent of each.*

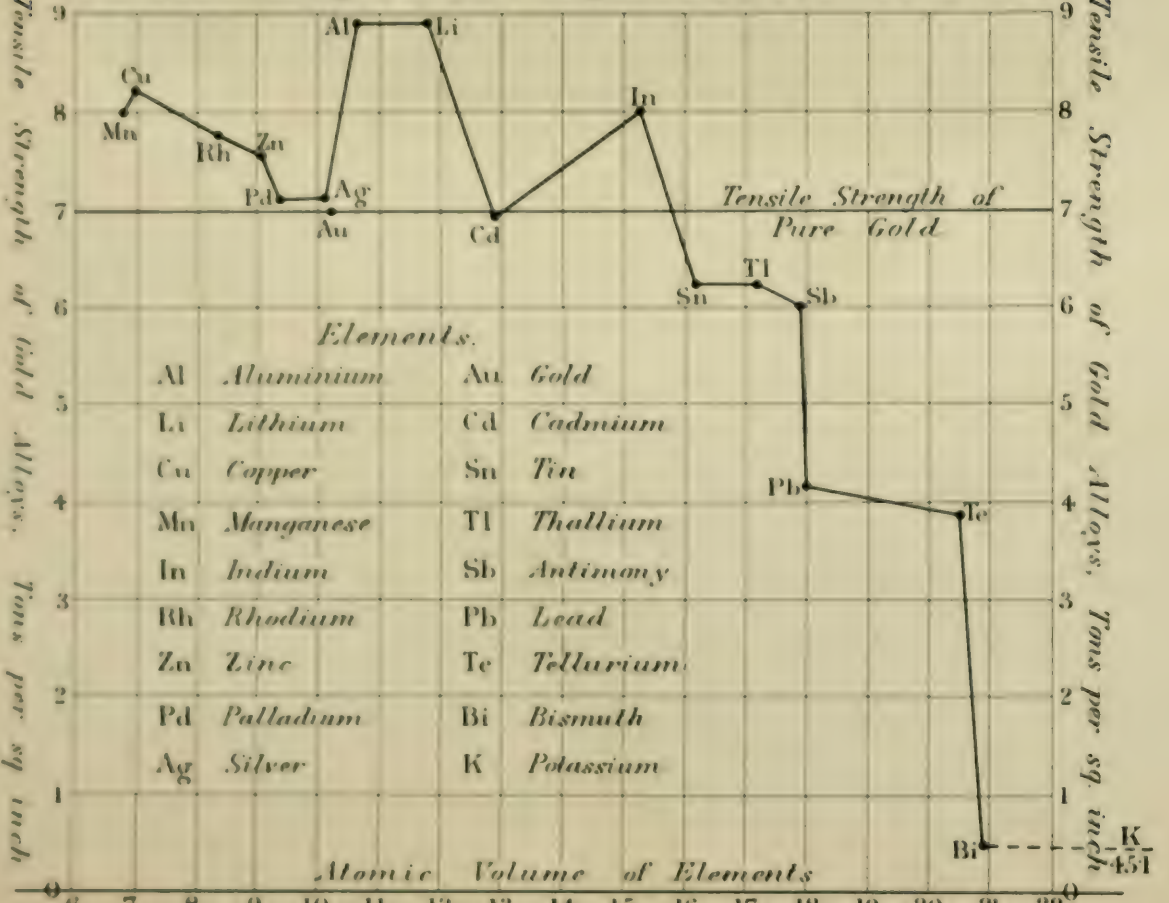

Fig 17. *Electro-deposited Iron heated in vacuum.*

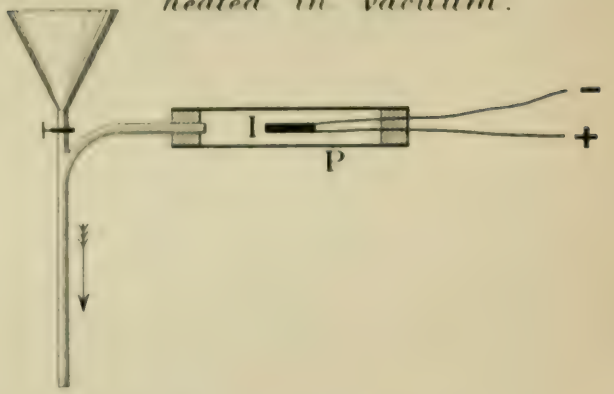

Fig 18. *Heating and Cooling of Electro-deposited Iron.*

Plate 122.

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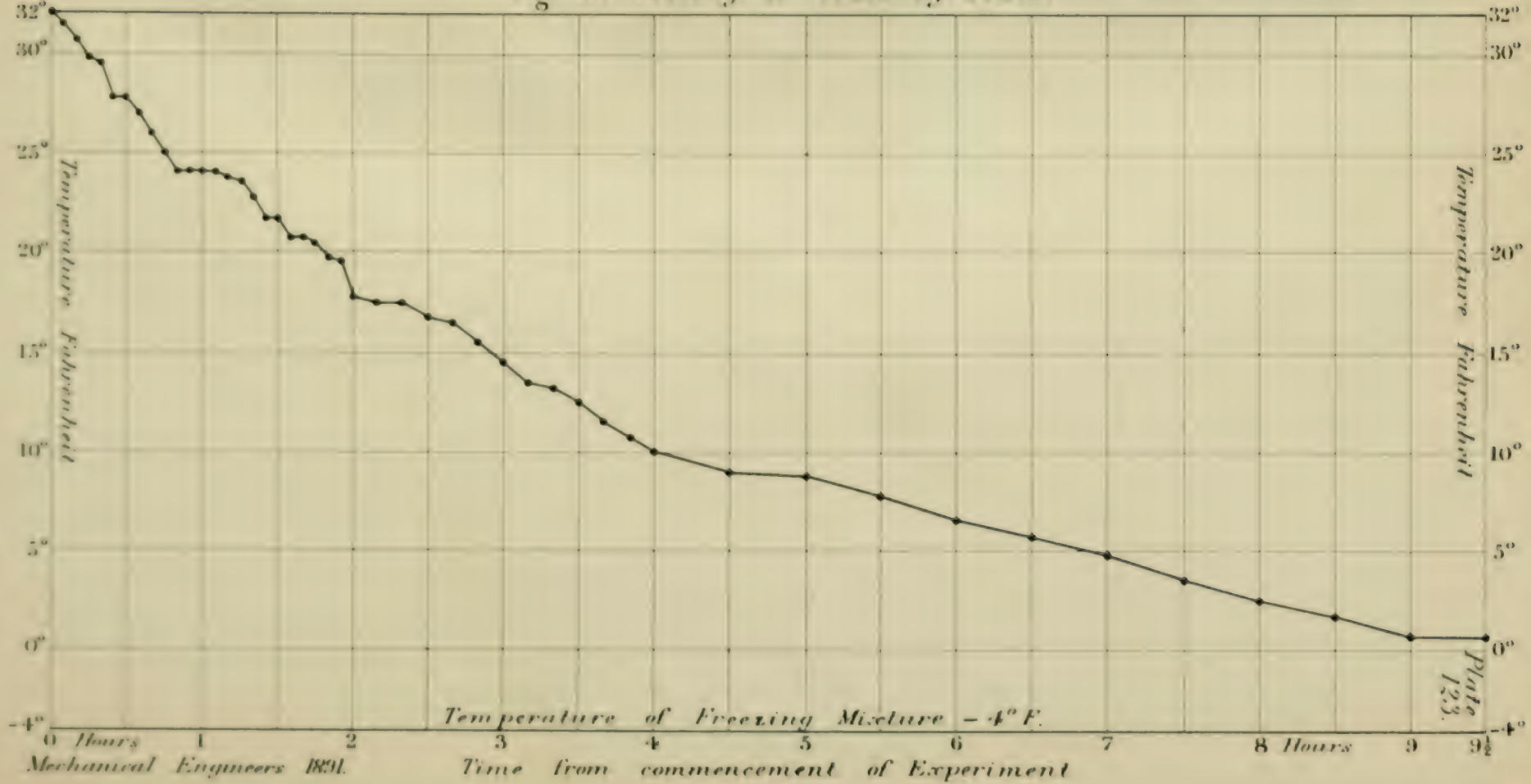
Fig. 19. *Cooling of Railway Axle.*



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